National Aeronautics and Space Administration

# FY 2017 BUDGET ESTIMATES

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# FY 2017 PRESIDENT'S BUDGET REQUEST SUMMARY

| | Fiscal Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Notional | | | |
| Budget Authority ($ in millions) | Operating Plan 2015 | Enacted 2016 | PBR 2017 | Mandatory 2017 | 2018 | 2019 | 2020 | 2021 |
| **NASA Total** | **18,010.2** | **19,285.0** | **19,025.1** | ***763.0*** | **18,826.6** | **19,399.9** | **19,879.9** | **20,367.5** |
| **Science** | **5,243.0** | **5,589.4** | **5,600.5** | ***298.0*** | **5,408.5** | **5,516.7** | **5,627.0** | **5,739.6** |
| **Earth Science** | **1,784.1** | **--** | **2,032.2** | ***60.0*** | **1,989.5** | **2,001.3** | **2,020.9** | **2,047.7** |
| **Planetary Science** | **1,446.7** | **--** | **1,518.7** | ***128.0*** | **1,439.7** | **1,520.1** | **1,575.5** | **1,625.7** |
| **Astrophysics** | **730.7** | **--** | **781.5** | ***85.0*** | **761.6** | **992.4** | **1,118.6** | **1,192.5** |
| **James Webb Space Telescope** | **645.4** | **620.0** | **569.4** | -- | **533.7** | **304.6** | **197.2** | **149.8** |
| **Heliophysics** | **636.1** | -- | **698.7** | ***25.0*** | **684.0** | **698.3** | **714.8** | **723.9** |
| **Aeronautics** | **642.0** | **640.0** | **790.4** | ***155.9*** | **846.4** | **1,060.1** | **1,173.3** | **1,286.9** |
| **Space Technology** | **600.3** | **686.5** | **826.7** | ***136.1*** | **704.4** | **718.5** | **732.9** | **747.5** |
| **Exploration** | **3,542.7** | **4,030.0** | **3,336.9** | ***173.0*** | **3,529.7** | **4,081.7** | **4,243.6** | **4,261.7** |
| **Exploration Systems Development** | **3,211.5** | **3,680.0** | **2,859.6** | ***173.0*** | **2,922.5** | **3,061.6** | **3,092.2** | **3,142.3** |
| **Exploration Research and Development** | **331.2** | **350.0** | **477.3** | -- | **607.2** | **1,020.1** | **1,151.4** | **1,119.5** |
| **Space Operations** | **4,625.5** | **5,029.2** | **5,075.8** | -- | **4,912.8** | **4,529.7** | **4,540.1** | **4,697.6** |
| **Space Shuttle** | **7.7** | **--** | **0.0** | **--** | **0.0** | **0.0** | **0.0** | **0.0** |
| **International Space Station** | **1,524.8** | **--** | **1,430.7** | **--** | **1,554.7** | **1,536.8** | **1,539.3** | **1,585.2** |
| **Space Transportation** | **2,254.0** | **--** | **2,757.7** | **--** | **2,475.0** | **2,118.7** | **2,144.4** | **2,213.9** |
| **Space and Flight Support (SFS)** | **839.0** | **--** | **887.4** | **--** | **883.2** | **874.1** | **856.4** | **898.6** |
| **Education** | **119.0** | **115.0** | **100.1** | -- | **102.1** | **104.1** | **106.2** | **108.3** |
| **Safety, Security, and Mission Services** | **2,754.6** | **2,768.6** | **2,836.8** | -- | **2,893.6** | **2,951.5** | **3,010.4** | **3,070.6** |
| **Center Management and Operations** | **2,023.7** | **--** | **2,017.7** | **--** | **2,058.1** | **2,113.5** | **2,155.6** | **2,198.8** |
| **Agency Management and Operations** | **730.9** | **--** | **819.1** | **--** | **835.5** | **838.0** | **854.8** | **871.8** |
| **Construction and Environmental Compliance and Restoration** | **446.1** | **388.9** | **419.8** | -- | **390.2** | **398.0** | **406.0** | **414.1** |
| **Construction of Facilities** | **374.4** | -- | **328.0** | **--** | **297.9** | **303.8** | **310.1** | **317.9** |
| **Environmental Compliance and Restoration** | **71.7** | -- | **91.8** | **--** | **92.3** | **94.2** | **95.9** | **96.2** |
| **Inspector General** | **37.0** | **37.4** | **38.1** | -- | **38.9** | **39.6** | **40.4** | **41.2** |
| **NASA Total** | **18,010.2** | **19,285.0** | **19,025.1** | ***763.0*** | **18,826.6** | **19,399.9** | **19,879.9** | **20,367.5** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

# FY 2017 PRESIDENT'S BUDGET REQUEST SUMMARY

| Budget Authority ($ in millions) | Operating Plan 2015 | Enacted 2016 | PBR 2017 | Mandatory 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|---|
| | | | Fiscal Year | | Notional | | | |
| **NASA Total** | **18,010.2** | **19,285.0** | **19,025.1** | *763.0* | **18,826.6** | **19,399.9** | **19,879.9** | **20,367.5** |
| **Science** | **5,243.0** | **5,589.4** | **5,600.5** | *298.0* | **5,408.5** | **5,516.7** | **5,627.0** | **5,739.6** |
| **Earth Science** | **1,784.1** | -- | **2,032.2** | *60.0* | **1,989.5** | **2,001.3** | **2,020.9** | **2,047.7** |
| **Earth Science Research** | **453.2** | -- | **501.7** | *30.0* | **472.9** | **461.3** | **475.9** | **484.2** |
| Earth Science Research and Analysis | 331.6 | -- | 360.7 | *30.0* | 322.6 | 312.4 | 322.4 | 326.7 |
| Computing and Management | 121.7 | -- | 141.0 | -- | 150.3 | 148.8 | 153.5 | 157.5 |
| **Earth Systematic Missions** | **827.3** | -- | **933.0** | -- | -- | **1,021.3** | **1,005.0** | **1,000.1** |
| Surface Water and Ocean Topography (SWOT) | 83.8 | -- | 83.7 | -- | 105.9 | 126.3 | 81.0 | 42.0 |
| NASA-ISRO Synthetic Aperture Radar (NISAR) | 50.6 | -- | 68.5 | -- | 85.0 | 150.0 | 145.0 | 100.0 |
| Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) | 126.5 | 117.4 | 112.4 | -- | 66.6 | 14.2 | 14.2 | 14.4 |
| GRACE Follow-On (GRACE-FO) | 84.7 | 59.9 | 33.7 | -- | 20.5 | 11.3 | 12.3 | 12.2 |
| Other Missions and Data Analysis | 481.8 | -- | 634.7 | -- | 687.5 | 719.5 | 752.6 | 831.6 |
| **Earth System Science Pathfinder** | **223.8** | -- | **296.0** | *30.0* | **248.6** | **216.7** | **227.8** | **245.1** |
| Venture Class Missions | 169.1 | -- | 194.3 | -- | 199.6 | 174.7 | 184.3 | 199.9 |
| Other Missions and Data Analysis | 54.6 | -- | 101.7 | *30.0* | 49.0 | 42.0 | 43.5 | 45.2 |
| **Earth Science Multi-Mission Operations** | **179.7** | -- | **191.8** | -- | **194.3** | **193.6** | **197.9** | **202.6** |
| **Earth Science Technology** | **59.7** | -- | **61.4** | -- | **60.4** | **59.7** | **62.7** | **63.7** |
| **Applied Sciences** | **40.4** | -- | **48.2** | -- | **47.9** | **48.7** | **51.5** | **52.0** |
| **Planetary Science** | **1,446.7** | -- | **1,518.7** | *128.0* | **1,439.7** | **1,520.1** | **1,575.5** | **1,625.7** |
| **Planetary Science Research** | **252.8** | -- | **284.7** | *16.0* | **271.6** | **285.7** | **281.6** | **287.3** |
| Planetary Science Research and Analysis | 162.4 | -- | 178.1 | *16.0* | 164.3 | 168.5 | 168.0 | 172.4 |
| Directorate Management | 4.0 | -- | 4.1 | -- | 4.1 | 4.1 | 4.1 | 4.1 |
| Near Earth Object Observations | 40.0 | -- | 50.0 | -- | 50.0 | 50.0 | 50.0 | 50.0 |
| Other Missions and Data Analysis | 46.4 | -- | 52.5 | -- | 53.2 | 63.2 | 59.5 | 60.8 |
| **Discovery** | **259.7** | -- | **202.5** | -- | -- | **337.4** | **345.0** | **405.3** |
| InSight | 170.0 | 92.1 | 13.3 | -- | 8.7 | 9.0 | 9.0 | -- |
| Other Missions and Data Analysis | 89.7 | -- | 189.2 | -- | 268.6 | 328.4 | 336.0 | 405.3 |
| **New Frontiers** | **286.0** | -- | **144.0** | *40.0* | **81.6** | **90.7** | **142.8** | **234.0** |
| Origins Spectral Interpretation Resource | 209.8 | 189.7 | 44.0 | -- | 38.1 | 43.1 | 27.7 | 16.5 |
| Other Missions and Data Analysis | 76.2 | -- | 100.0 | *40.0* | 43.5 | 47.6 | 115.1 | 217.5 |
| **Mars Exploration** | **305.0** | -- | **584.8** | *29.0* | **588.8** | **565.0** | **498.4** | **279.9** |
| Mars Rover 2020 | 103.6 | -- | 377.5 | | 409.0 | 381.0 | 322.0 | 140.0 |
| Other Missions and Data Analysis | 201.4 | -- | 207.3 | *29.0* | 179.8 | 184.0 | 176.4 | 139.9 |
| **Outer Planets & Ocean Worlds** | **184.0** | -- | **137.3** | *33.0* | **56.0** | **77.8** | **128.0** | **247.3** |
| Jupiter Europa | 100.0 | 175.0 | 49.6 | 33.0 | 24.2 | 65.2 | 117.5 | 236.5 |
| **Technology** | **159.2** | -- | **165.5** | *10.0* | **164.4** | **163.5** | **179.7** | **172.0** |

# FY 2017 PRESIDENT'S BUDGET REQUEST SUMMARY

| | Fiscal Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Operating Plan 2015 | Enacted 2016 | PBR 2017 | Mandatory 2017 | Notional 2018 | 2019 | 2020 | 2021 |
| **Astrophysics** | **730.7** | **--** | **781.5** | ***85.0*** | **761.6** | **992.4** | **1,118.6** | **1,192.5** |
| **Astrophysics Research** | **201.7** | **--** | **226.1** | ***3.0*** | **236.3** | **235.7** | **248.5** | **252.0** |
| STEM Education | 42.0 | -- | 25.0 | -- | **25.0** | **25.0** | **25.0** | **25.0** |
| Astrophysics Research and Analysis | 71.1 | -- | 72.7 | *3.0* | 73.0 | 73.0 | 73.0 | 73.0 |
| Balloon Project | 38.0 | -- | 37.0 | -- | 37.3 | 37.4 | 38.9 | 40.4 |
| Other Missions and Data Analysis | 50.6 | -- | 91.4 | -- | 101.0 | 100.3 | 111.6 | 113.6 |
| **Cosmic Origins** | **201.0** | **--** | **198.5** | **--** | **198.4** | **197.3** | **195.5** | **209.5** |
| Hubble Space Telescope Operations | 98.6 | -- | 97.3 | -- | 98.3 | 98.3 | 98.3 | 98.3 |
| Stratospheric Observatory for Infrared Astronomy (SOFIA) | 70.0 | -- | 83.8 | -- | 84.8 | 84.8 | 84.8 | 84.8 |
| Other Missions and Data Analysis | 32.4 | -- | 17.4 | -- | 15.3 | 14.2 | 12.4 | 26.4 |
| **Physics of the Cosmos** | **104.1** | **--** | **94.1** | ***6.0*** | **88.0** | **94.1** | **97.7** | **94.0** |
| **Exoplanet Exploration** | **100.6** | **--** | **133.8** | ***76.0*** | **148.0** | **309.3** | **373.3** | **450.8** |
| **Astrophysics Explorer** | **123.3** | **--** | **129.0** | **--** | **91.0** | **156.0** | **203.5** | **186.2** |
| Transiting Exoplanet Survey Satellite (TESS) | 80.1 | 73.5 | 87.0 | -- | 27.9 | 9.1 | 2.5 | -- |
| Other Missions and Data Analysis | 43.2 | -- | 42.0 | -- | 63.1 | 146.9 | 201.1 | 186.2 |
| **James Webb Space Telescope** | **645.4** | **620.0** | **569.4** | **--** | **533.7** | **304.6** | **197.2** | **149.8** |
| **Heliophysics** | **636.1** | **--** | **698.7** | ***25.0*** | **684.0** | **698.3** | **714.8** | **723.9** |
| **Heliophysics Research** | **192.0** | **--** | **180.1** | ***15.0*** | **192.0** | **210.0** | **215.9** | **214.2** |
| Heliophysics Research and Analysis | 34.1 | -- | 38.9 | *5.0* | 48.9 | 53.9 | 53.9 | 53.9 |
| Sounding Rockets | 66.2 | -- | 53.3 | -- | 59.0 | 61.1 | 63.1 | 63.1 |
| Research Range | 21.3 | -- | 21.7 | -- | 21.7 | 25.1 | 25.1 | 25.2 |
| Other Missions and Data Analysis | 70.4 | -- | 66.2 | *10.0* | 62.4 | 70.0 | 73.7 | 71.9 |
| **Living with a Star** | **263.5** | **--** | **374.2** | ***10.0*** | **398.7** | **244.6** | **135.8** | **127.3** |
| Solar Probe Plus (SPP) | 193.7 | 238.6 | 232.5 | -- | 289.7 | 100.4 | 30.6 | 22.1 |
| Solar Orbiter Collaboration (SOC) | 20.5 | 49.8 | 80.7 | -- | 51.4 | 66.3 | 2.3 | 2.4 |
| Other Missions and Data Analysis | 49.4 | -- | 61.0 | *10.0* | 57.7 | 77.9 | 103.0 | 102.8 |
| **Solar Terrestrial Probes** | **70.6** | **--** | **39.8** | **--** | **38.8** | **127.3** | **179.4** | **198.4** |
| **Heliophysics Explorer Program** | **110.0** | **--** | **104.6** | **--** | **54.5** | **116.3** | **183.8** | **184.0** |
| Ionospheric Connection Explorer (ICON) | 61.0 | 48.4 | 49.4 | -- | 9.0 | 4.5 | 1.3 | -- |
| Other Missions and Data Analysis | 48.9 | -- | 55.2 | -- | 45.6 | 111.8 | 182.5 | 184.0 |

# FY 2017 PRESIDENT'S BUDGET REQUEST SUMMARY

| | Fiscal Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Operating Plan 2015 | Enacted 2016 | PBR 2017 | Mandatory 2017 | Notional 2018 | 2019 | 2020 | 2021 |
| **Aeronautics** | **642.0** | **640.0** | **790.4** | ***155.9*** | **846.4** | **1,060.1** | **1,173.3** | **1,286.9** |
| **Aeronautics** | **642.0** | **640.0** | **790.4** | ***155.9*** | **846.4** | **1,060.1** | **1,173.3** | **1,286.9** |
| **Airspace Operations and Safety Program** | **154.0** | **--** | **159.4** | ***18.0*** | **159.2** | **176.2** | **189.1** | **221.5** |
| **Advanced Air Vehicles Program** | **240.6** | **--** | **298.6** | ***30.0*** | **277.4** | **308.8** | **311.6** | **312.6** |
| **Integrated Aviation Systems Program** | **150.0** | **--** | **210.0** | ***92.9*** | **255.4** | **381.4** | **493.0** | **556.7** |
| **Transformative Aero Concepts Program** | **97.4** | **--** | **122.3** | ***15.0*** | **154.4** | **193.8** | **179.7** | **196.2** |
| **Space Technology** | **600.3** | **686.5** | **826.7** | ***136.1*** | **704.4** | **718.5** | **732.9** | **747.5** |
| **Space Technology** | **600.3** | **--** | **826.7** | ***136.1*** | **704.4** | **718.5** | **732.9** | **747.5** |
| **Agency Technology and Innovation** | **31.3** | **--** | **34.3** | **--** | **35.0** | **35.7** | **36.4** | **37.1** |
| **SBIR and STTR** | **190.7** | **--** | **213.0** | **--** | **213.2** | **213.5** | **213.8** | **213.8** |
| **Space Technology Research and Development** | **378.3** | **--** | **579.4** | ***136.1*** | **456.2** | **469.3** | **482.7** | **496.6** |
| *TDM RESTORE-L* | -- | *133.0* | *130.0* | *65.0* | *66.3* | *67.6* | *69.0* | *70.4* |
| **Exploration** | **3,542.7** | **4,030.0** | **3,336.9** | ***173.0*** | **3,529.7** | **4,081.7** | **4,243.6** | **4,261.7** |
| **Exploration Systems Development** | **3,211.5** | **3,680.0** | **2,859.5** | ***173.0*** | **2,922.5** | **3,061.6** | **3,092.2** | **3,142.3** |
| **Orion Program** | **1,190.2** | **1,270.0** | **1,119.8** | ***66.4*** | **1,119.9** | **1,123.9** | **1,135.1** | **1,153.3** |
| Crew Vehicle Development | 1,179.7 | 1,251.5 | 1,109.3 | *66.4* | 1,109.4 | 1,113.4 | 1,124.6 | 1,142.7 |
| Orion Program Integration and Support | 10.5 | -- | 10.5 | -- | 10.5 | 10.5 | 10.5 | 10.7 |
| **Space Launch System (SLS)** | **1,678.6** | **2,000.0** | **1,310.3** | ***80.4*** | **1,361.4** | **1,484.7** | **1,499.6** | **1,524.2** |
| Launch Vehicle Development | 1,646.6 | 1,950.0 | 1,262.8 | *80.4* | 1,295.0 | 1,419.7 | 1,431.5 | 1,454.6 |
| SLS Program Integration and Support | 32.0 | -- | 47.5 | -- | 66.5 | 65.0 | 68.1 | 69.6 |
| **Exploration Ground Systems (EGS)** | **342.8** | **410.0** | **429.4** | ***26.2*** | **441.2** | **453.0** | **457.5** | **464.7** |
| EGS Development | 305.9 | 390.9 | 414.1 | *26.2* | 425.9 | 437.7 | 442.1 | 449.1 |
| EGS Program Integration and Support | 36.9 | -- | 15.3 | -- | 15.3 | 15.3 | 15.4 | 15.7 |
| **Exploration Research and Development** | **331.2** | **350.0** | **477.3** | **--** | **607.2** | **1,020.1** | **1,151.4** | **1,119.5** |
| **Human Research Program** | **142.0** | **--** | **153.3** | **--** | **178.2** | **178.2** | **180.0** | **182.8** |
| **Advanced Exploration Systems** | **189.2** | **--** | **324.1** | **--** | **429.0** | **842.0** | **971.4** | **936.6** |
| **Space Operations** | **4,625.5** | **5,029.2** | **5,075.8** | **--** | **4,912.8** | **4,529.7** | **4,540.1** | **4,697.6** |
| **Space Shuttle** | **7.7** | **--** | **--** | **--** | **--** | **--** | **--** | **--** |
| **International Space Station** | **1,524.8** | **--** | **1,430.7** | **--** | **1,554.7** | **1,536.8** | **1,539.3** | **1,585.2** |
| **International Space Station Program** | **1,524.8** | **--** | **1,430.7** | **--** | **1,554.7** | **1,536.8** | **1,539.3** | **1,585.2** |
| ISS Systems Operations and Maintenance | 1,113.0 | -- | 1,108.9 | -- | 1,245.6 | 1,196.3 | 1,192.6 | 1,232.5 |
| ISS Research | 411.8 | -- | 321.9 | -- | 309.1 | 340.5 | 346.7 | 352.6 |

# FY 2017 PRESIDENT'S BUDGET REQUEST SUMMARY

| | Fiscal Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Operating Plan 2015 | Enacted 2016 | PBR 2017 | Mandatory 2017 | Notional 2018 | 2019 | 2020 | 2021 |
| **Space Transportation** | **2,254.0** | **--** | **2,757.7** | **--** | **2,475.0** | **2,118.7** | **2,144.4** | **2,213.9** |
| **Commercial Crew** | **805.0** | **--** | **1,184.8** | **--** | **731.9** | **173.1** | **35.8** | **36.3** |
| **Crew and Cargo** | **1,449.0** | **--** | **1,572.8** | **--** | **1,743.0** | **1,945.6** | **2,108.6** | **2,177.6** |
| **Space and Flight Support (SFS)** | **839.0** | **--** | **887.4** | **--** | **883.2** | **874.1** | **856.4** | **898.6** |
| **21st Century Space Launch Complex** | **35.2** | **--** | **12.0** | **--** | **--** | **--** | **--** | **--** |
| **Space Communications and Navigation** | **579.1** | **--** | **612.4** | **--** | **616.1** | **597.6** | **576.4** | **614.6** |
| Space Communications Networks | 516.3 | -- | 526.0 | -- | 532.1 | 476.3 | 421.9 | 465.0 |
| Space Communications Support | 62.8 | -- | 86.3 | -- | 84.0 | 121.3 | 154.5 | 149.6 |
| **Human Space Flight Operations** | **99.7** | **--** | **128.3** | **--** | **130.4** | **139.9** | **142.0** | **143.8** |
| **Launch Services** | **80.6** | **--** | **87.2** | **--** | **89.1** | **89.1** | **90.0** | **91.4** |
| **Rocket Propulsion Test** | **44.4** | **--** | **47.6** | **--** | **47.6** | **47.6** | **48.0** | **48.8** |
| **Education** | **119.0** | **115.0** | **100.1** | **--** | **102.1** | **104.1** | **106.2** | **108.3** |
| **Education** | **119.0** | **115.0** | **100.1** | **--** | **102.1** | **104.1** | **106.2** | **108.3** |
| **Aerospace Research and Career Development** | **58.0** | **--** | **33.0** | **--** | **33.0** | **33.0** | **33.0** | **33.0** |
| National Space Grant College and Fellowship Program (Space Grant) | 40.0 | 40.0 | 24.0 | -- | 24.0 | 24.0 | 24.0 | 24.0 |
| Experimental Program to Stimulate Competitive Research (EPSCoR) | 18.0 | 18.0 | 9.0 | -- | 9.0 | 9.0 | 9.0 | 9.0 |
| **STEM Education and Accountability** | **61.0** | **--** | **67.1** | **--** | **69.1** | **71.1** | **73.2** | **75.3** |
| Minority University Research Education Project | 32.0 | -- | 30.0 | -- | 30.0 | 30.0 | 30.0 | 30.0 |
| STEM Education and Accountability Projects | 29.0 | -- | 37.1 | -- | 39.1 | 41.1 | 43.2 | 45.3 |
| **Safety, Security, and Mission Services** | **2,754.6** | **2,768.6** | **2,836.8** | **--** | **2,893.6** | **2,951.5** | **3,010.4** | **3,070.6** |
| **Center Management and Operations** | **2,023.7** | **--** | **2,017.7** | **--** | **2,058.1** | **2,113.5** | **2,155.6** | **2,198.8** |
| Center Institutional Capabilities | 1,574.8 | -- | 1,563.8 | -- | 1,596.7 | 1,636.9 | 1,665.1 | 1,696.1 |
| Center Programmatic Capabilities | 448.9 | -- | 453.8 | -- | 461.4 | 476.6 | 490.5 | 502.7 |

# FY 2017 PRESIDENT'S BUDGET REQUEST SUMMARY

| | Fiscal Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Operating Plan 2015 | Enacted 2016 | PBR 2017 | Mandatory 2017 | Notional 2018 | 2019 | 2020 | 2021 |
| **Agency Management and Operations** | **730.9** | **--** | **819.2** | **--** | **835.5** | **838.0** | **854.8** | **871.8** |
| **Agency Management** | **363.6** | **--** | **377.5** | **--** | **385.1** | **395.6** | **403.5** | **411.6** |
| **Safety and Mission Success** | **164.9** | **--** | **170.4** | **--** | **173.8** | **178.5** | **182.1** | **185.7** |
| Safety and Mission Assurance | 48.7 | -- | 51.2 | -- | 52.2 | 53.6 | 54.7 | 55.8 |
| Chief Engineer | 82.6 | -- | 86.1 | -- | 87.8 | 90.2 | 92.0 | 93.8 |
| Chief Health and Medical Officer | 4.2 | -- | 4.1 | -- | 4.2 | 4.3 | 4.4 | 4.5 |
| Independent Verification and Validation | 29.4 | -- | 29.0 | -- | 29.6 | 30.4 | 31.0 | 31.6 |
| **Agency IT Services (AITS)** | **175.5** | **--** | **244.3** | **--** | **249.1** | **235.6** | **240.3** | **245.0** |
| IT Management | 14.6 | -- | -- | -- | 17.4 | 18.8 | 20.4 | 25.2 |
| Applications | 62.8 | -- | 58.0 | -- | 59.6 | 61.2 | 62.6 | 63.7 |
| Infrastructure | 98.0 | -- | 166.3 | -- | 172.1 | 155.6 | 157.3 | 156.1 |
| **Strategic Capabilities Asset Program** | **26.9** | **--** | **27.0** | **--** | **27.5** | **28.3** | **28.9** | **29.5** |
| **Construction and Environmental Compliance and Restoration** | **446.1** | **388.9** | **419.8** | **--** | **390.2** | **398.0** | **406.0** | **414.1** |
| **Construction of Facilities (CoF)** | **374.4** | **--** | **328.0** | **--** | **297.9** | **303.8** | **310.1** | **317.9** |
| **Institutional CoF** | **276.5** | **--** | **290.7** | **--** | **297.9** | **303.8** | **310.1** | **317.9** |
| **Exploration CoF** | **67.9** | **--** | **8.8** | **--** | **--** | **--** | **--** | **--** |
| **Space Operations CoF** | **19.3** | **--** | **28.5** | **--** | **--** | **--** | **--** | **--** |
| **Aeronautics CoF** | **9.0** | **--** | **--** | **--** | **--** | **--** | **--** | **--** |
| **Science CoF** | **1.7** | **--** | **--** | **--** | **--** | **--** | **--** | **--** |
| **Environmental Compliance and Restoration** | **71.7** | **--** | **91.8** | **--** | **92.3** | **94.2** | **95.9** | **96.2** |
| **Inspector General** | **37.0** | **37.4** | **38.1** | **--** | **38.9** | **39.6** | **40.4** | **41.2** |
| **NASA Total** | **18,010.2** | **19,285.0** | **19,025.1** | ***763.0*** | **18,826.6** | **19,399.9** | **19,879.9** | **20,367.5** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

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# FY 2017 BUDGET REQUEST EXECUTIVE SUMMARY

## Overview

### Agency Summary

# MESSAGE FROM THE ADMINISTRATOR

It is my privilege to present President Obama's FY 2017 $19 billion budget request for NASA.

NASA innovation drives our journey to Mars, and breakthroughs in aviation and space technologies are improving life on Earth, making it possible to better understand our home planet even as we look out to the stars. Our Nation's space program is well positioned to continue the United States' world leadership in innovation and exploration.

President Obama's strong investment in NASA throughout his administration has brought us closer to the Red Planet than ever before, helped bring to maturity a new commercial sector devoted to bringing cargo and crew to low Earth orbit, and advanced our scientific inquiry and technological capabilities on many fronts. Space is good for the economy and the human spirit. It's uniting our world and inspiring the next generation of leaders who will craft a future that builds on the work we do today.

This year we unveiled the previously mysterious Pluto while making progress on the James Webb Space Telescope, the next great observatory that will peer into other galaxies and help us understand the foundations of our universe. Astronauts marked an incredible 15 years of continuous habitation aboard the International Space Station and achieved milestones in research and human health that will help to extend human presence farther into the solar system. New technologies leapt from drawing board to development, and our aeronautics research transferred technologies to broader use and brought us closer to the Next Generation of safer and more efficient air traffic management.

At the core of everything we do, is a vision for the future where we are engaged in a mission of exploration that improves lives and increases knowledge while achieving previously impossible goals for humanity. The President's Budget keeps us on a strong and strategic course of achievable goals that will enable us to maximize what we have learned in low Earth orbit as we move toward increasingly challenging missions in cis-lunar space and eventually to Mars where explorers will be virtually independent of Earth.

The FY 2017 Budget gives NASA the flexibility and ability to pursue bold new missions to places like the outer planets and to invest even more strongly in aeronautics technologies that will make our air traffic system safer, cleaner, and more efficient for millions of travelers worldwide. It enables NASA to continue the momentum building around the Space Launch System rocket and the Orion spacecraft, which will carry humans to deep space in the coming years, as well as the cutting edge technologies in life support, habitation systems, propulsion, and other areas that will help make this goal achievable. It enables industry to continue building the space transportation systems of tomorrow for cargo and crew and restore our capability to launch astronauts from American soil.

Our work is part of a vital strategy to equip our Nation with the technologies for the future and inspire a new generation of explorers to make the next giant leaps in human experience. This budget represents an investment in America's future and positions our country to reach new heights in discovery, job creation, and economic growth.

Charles F. Bolden, Jr.

NASA Administrator

# BUDGET HIGHLIGHTS

The National Aeronautics and Space Act of 1958 challenged our Nation to grow our technical and scientific abilities in air and space. NASA-funded R&D helps stimulate our long-term capacity for innovation and economic growth within the government, at universities, and at industrial companies. The disciplines NASA advances are many – including materials, computing and electronics, fuels, radio communications, safety, and even human health. Most importantly, NASA has driven forward the state of the art in the air and in space, making air travel safer, less expensive, and less polluting, and opening the space frontier for the Nation and all mankind through robotic and human space missions and the development of new technology.

The FY 2017 President's Budget advances the Nation's space exploration, technology development, and scientific research plans and maintains the U.S. status as a world leader in space through the development of a next-generation deep space transportation system. It fosters the development of a commercial space industry that will, among other things, make space transportation safer and more affordable, and expand the utility of the International Space Station (ISS) as a research laboratory. The budget ensures we continue to learn about and protect life on our home planet, Earth. It invests in research, technology development, and a scientific infrastructure that enables exploration today, tomorrow, and generations from now. Moreover, the FY 2017 Budget aims to create jobs and support the growing U.S. economy.

In FY 2017, NASA continues to plan for our first steps beyond low Earth orbit since the Apollo era. NASA will continue to refine the requirements for its first-of-a-kind mission to capture and redirect a near-Earth asteroid into a stable orbit around the Moon, where astronauts will explore the asteroid. This activity draws on the expertise of scientists, mission managers, technologists, and operations specialists from across the agency as we learn to operate and live safely beyond the Earth for extended periods of time and drive towards future human missions to Mars. The Agency will continue to strive to understand and mitigate the effects of long-term human exposure to space and develop the technologies and mature the systems required for deep-space missions. In FY 2017, NASA will also continue work through public-private partnerships on the next element of the agency's capability-driven architecture: the development of habitation systems that will enable astronauts to live for extended periods beyond low Earth orbit – initially in cis-lunar space.

The FY 2017 budget request fully supports the plan for crewed exploration of deep space. The Orion Program, Space Launch System (SLS) Program, and Exploration Ground System Program completed their Critical Design Reviews demonstrating the Programs are appropriately mature to continue with the final design and fabrication phases. NASA is on track for a launch capability readiness date of November 2018 for Exploration Mission 1 (EM-1), which will be an uncrewed test of the SLS rocket carrying an Orion capsule.

NASA continues to reduce the barriers to human and robotic space activities by identifying and working solutions for both near and long-term needs. The Agency's investments in Space Technology in FY 2017 include demonstrations of maturing technologies, and novel "game-changing" research and experimental developments that are the most likely to improve our capabilities in space. Focus areas in 2017 include solar electric propulsion, which enable a variety of deep space missions, including the asteroid mission; laser communications; and human-robotic interfaces. NASA's Space Technology program also supports Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) programs. Through these competitive opportunities, NASA is able to draw on the innovation of small local engineering and technology companies. These programs are a win-win as NASA benefits from the creativity and flexibility of small teams, and the companies grow and may be able to spin off NASA-inspired technologies to new commercial markets.

# BUDGET HIGHLIGHTS

In January 2014, the President's Science Advisor announced plans to extend ISS operations to at least 2024. Doing so increases the Nation's ability to conduct fundamental and applied research necessary to developing spacecraft and human life support systems for deep space exploration. The ISS extension is made possible in large part because of the success of our commercial space partners in developing low-cost and reliable systems for delivering supplies and equipment to the ISS. The burgeoning U.S. commercial space marketplace is already providing mission support, which lessens American reliance on foreign services, and creates high-skilled jobs across the Nation.

This budget request strongly supports ISS research. Scientists and engineers will develop and execute experiments and technology demonstrations in diverse disciplines including physics, biology, materials science, robotics, communications, and human physiology. Insights gained from these studies will be essential for planning future deep space missions, including to Mars. The Center for the Advancement of Science in Space (CASIS), the research management organization for the ISS National Laboratory, will continue to enable federal, academic, and commercial research activities. Exciting research will include potential medicines and interventions that will improve human health both in space and here on Earth.

The FY 2017 budget request for Aeronautics research includes significant new investment in the flight demonstration of advanced technologies, reflecting its focus on six strategic areas: safe, efficient growth in global operations; innovation in commercial supersonic aircraft; ultra-efficient commercial vehicles; transition to low-carbon propulsion; real-time, system-wide safety assurance; and assured autonomy for aviation transformation. Across its portfolio of aeronautics investments, NASA continues to develop and test solutions that strengthen the air travel and transportation industry while minimizing environmental impact. In particular, the new investments in technologies that will make air travel cleaner and more efficient are a key part of the Administration's 21st Century Clean Transportation Plan.

This budget request continues to fund a strategic suite of missions to study the Earth, Sun, solar system, and deep space. Earth observations continue to allow unprecedented study of climate change, weather, and natural hazards. NASA investments in improved IT systems capable of managing "big data" will provide researchers with unparalleled access to data about the Earth. By fostering collective and collaborative research, the scientific insights gained from NASA missions will increase profoundly. NASA will also support the Administration's Space Weather Action Plan and Space Weather Strategy, designed to reduce threats to the nation from space weather.

The James Webb Space Telescope (Webb) remains on track for launch in 2018. Once operational, scientists will be able to look farther out into space than ever before, gaining new insights to the formation and evolution of stars and galaxies. A robust planetary science program includes data analysis of ongoing missions, and development of the next Mars rover. NASA will also continue formulating a mission to Europa, Jupiter's icy moon that, data suggests, may have organic material on its surface.

NASA supports efforts to improve the quality and delivery of science, technology, engineering, and mathematics (STEM) education programs. The Office of Education will continue to coordinate with the Department of Education, the National Science Foundation, and the Smithsonian Institution on STEM issues in order to maximize NASA's unique resources that support the Federal STEM Education Five-Year Strategic Plan. Using competitive processes, NASA will continue to identify and support the most effective STEM education activities across the agency.

The President joined other world leaders at the recent Paris climate negotiations to launch Mission Innovation, a landmark commitment to dramatically accelerate public and private global clean energy innovation, by investing in new technologies that will define a clean, affordable, and reliable global power mix. Through this initiative, the U.S. and 19 other countries have committed to doubling their governmental clean energy research and development investment over five years. Successful innovation in clean energy requires broad participation, including nontraditional approaches and innovators close to stakeholders that will benefit from clean energy solutions. Mission Innovation provides a robust framework to expand and better integrate clean energy research across agencies. The Budget for NASA includes over $400 million for Aeronautics investments ($321.1 million discretionary and $100.0 million mandatory) that will focus on exploration of new ideas and concepts that will revolutionize the aviation industry with the potential of reducing aviation's impact on the environment, as well as $34 million (discretionary) in Space Technology investments in technologies for advanced power generation and storage (such as green propellant, fuel cells and batteries), Earth environment sensing technologies, and technologies to obtain oxygen from carbon dioxide.

The FY 2017 budget makes efficient use of NASA's assets, including its workforce, equipment, and one-of-a-kind facilities. The budget also includes reinvigorated efforts to protect these assets, particularly from cyber threats. NASA continues to evaluate its current and future needs for existing facilities and invests in preventative repairs that will reduce future costs of refurbishment or replacement. The Agency is also proactively seeking means to reduce its operating costs. NASA is reducing its energy footprint, working with other agencies to share and leverage facilities usage, and using reimbursable agreements to support external customers who seek NASA's unique capabilities.

In its more than 50 years, NASA has advanced our technical knowledge and human abilities. Our engineers are now building spacecraft capable of launching humans to another planet or moving an asteroid. What we now know about the stars and planets would astound the earliest scientists who documented the seasonality of constellations, or those who later studied the heavens through simple lenses and prisms. In many respects, NASA has made science fiction a reality by investing in disciplines that may have seemed like fantasy in 1958: robotics, space habitats, analyzing the surface of Mars, and healing the sick through telemedicine. But in one important respect, NASA continues to do what it has always done. It serves as a stimulus to U.S. creativity and innovation, our competitiveness on the global stage, and economic growth that benefits all Americans.

## SCIENCE IS ANSWERING ENDURING QUESTIONS IN, FROM, AND ABOUT SPACE

NASA's Science account funds exploration of our planet, other planets and planetary bodies, our star system in its entirety, and funds observations out into our galaxy and beyond. Through the development of space observatories and probes that enable exploration and discovery, NASA will continue to inspire the next generation of scientists, engineers, and explorers. The FY 2017 budget request for Science is $5,600.5 million.

Webb, a successor to the Hubble telescope, is on schedule for a 2018 launch. Webb will be 100 times more capable than Hubble, becoming the premier astronomical observatory of the next decade. The request also funds ongoing study of a possible Wide Field Infrared Survey Telescope / Astrophysics Focused Telescope Assets (WFIRST/AFTA) mission, the next major observatory beyond James Webb and the highest-priority large mission in the Decadal Survey. Astrophysics Explorer missions in formulation and development include the Transiting Exoplanet Survey Satellite (TESS), and the Neutron star Interior Composition ExploreR (NICER) mission. TESS will identify planets around bright stars, surveying 400 times as much sky as any previous exoplanet mission. NICER will study the extraordinary gravitational, electromagnetic, and nuclear-physics environments of neutron stars. The request also includes full funding for the Stratospheric Observatory for Infrared Astronomy (SOFIA), which will be subject to the 2018 Senior Review for Astrophysics.

NASA continues to learn more about Earth. The Sustainable Land Imaging program will provide U.S. users with high-quality, global, land imaging measurements that are compatible with the existing 43-year Landsat record; that will address near- and longer-term issues of continuity risk; and that will evolve flexibly and responsibly through investment in, and introduction of, new sensor and system technologies. This budget supports launch of Landsat 9 as early as 2021. The request fully funds Ice, Cloud, and land Elevation Satellite (ICESat-II); Gravity Recovery and Climate Experiment (GRACE-FO); and many other future Earth Science missions.

The OSIRIS-REx spacecraft will launch in fall of 2016, travel to a near-Earth asteroid in 2018 and be the first U.S. mission to carry samples from an asteroid back to Earth. The request supports the Mars 2020 lander and a potential future mission to Jupiter's moon Europa. Due to cancellation of the March 2016 launch opportunity, plans for the InSight mission to study the deep interior of Mars are currently under review.

The request fully funds several major missions to advance our understanding of the Sun and its impact on the Earth, including Solar Probe Plus (SPP) and Solar Orbiter Collaboration (SOC). The request also funds the Ionospheric Connection Explorer (ICON) and Global-scale Observations of the Limb and Disk (GOLD) Explorer missions. ICON's goal is to understand the tug-of-war between Earth's atmosphere and the space environment, in the "no man's land" of the ionosphere, while GOLD will measure densities and temperatures in Earth's thermosphere and ionosphere. The request includes NASA work in support of the Administration's Space Weather Action Plan and Space Weather Strategy, and also increases investments in cubesats and small spacecraft technology development, including studies of constellations of small spacecraft, with the aim of reducing the costs of future missions.

## AERONAUTICS RESEARCH TO ADDRESS AVIATION'S CHALLENGES

The air transportation system of today is a vital part of the U.S. and Global economies. It is the primary mechanism for connecting major population centers in the U.S. and countries across the world for people and cargo. NASA conducts aeronautics research to bring transformational advances in the safety, capacity, and efficiency of the air transportation system while minimizing negative impacts on the environment. The FY 2017 budget request for the Aeronautics account is $790.4 million.

The FY 2017 budget request for NASA Aeronautics will demonstrate and validate concepts that enable breakthroughs in speed and efficiency of aircraft, simultaneously opening new markets for U.S. industry while minimizing environmental impact. The multi-year investment will test cutting-edge technologies in realistic environments and enable their widespread adoption through: demonstrating and validating new configurations and technologies to achieve a 50 percent reduction in fuel consumption while also dramatically reducing noise; developing a series of transformative hybrid electric propulsion demonstrators focused on propulsion innovation for subsonic transport class aircraft; and developing a supersonic low boom flight demonstrator to validate technologies for quiet supersonic flight and utilize bio-fuels.

# BUDGET HIGHLIGHTS

## SPACE TECHNOLOGY GROWS CAPABILITIES, REDUCES COSTS, AND DRIVES EXPLORATION

Space Technology conducts rapid development and incorporation of transformative space technologies that enable and reduce the cost of NASA's missions and increase the capabilities of other U.S. agencies and the U.S. space industry. Technology drives exploration by improving our ability to access and travel through space; land more massive systems more accurately in more locations throughout the solar system; live and work in deep space and on planetary bodies; transform the ability to observe the universe to answer profound questions in earth and space sciences; and improve the U.S. aerospace industry technological capability to continue the Nation's economic leadership. The FY 2017 budget request for Space Technology is $826.7 million

The FY 2017 budget support formulation of Restore-L, which will build on the Robotic Refueling Mission technology demonstrations on ISS in advancing servicing technologies and transferring the technologies for commercialization. Space Technology continues development of high-powered solar electric propulsion (SEP) technologies that will enable extremely efficient orbit transfer and accommodate increasing power demands for satellites. The Agency plans to incorporate high power SEP technology in the robotic segment of the asteroid redirect mission. In addition, over the next year, Space Technology will execute several in-space demonstrations including a deep space atomic clock for advanced navigation and four small spacecraft demonstrations of pioneering new technologies. Space Technology will continue maturation of enabling technologies for future human and robotic exploration missions including deep space optical communications to return more data and improve operations; improved carbon dioxide removal and oxygen recovery systems for more efficient life support and environmental control capabilities; robotics and autonomy to reduce mission cost and risk; and advancements in remote sensing instruments and spacecraft subsystems to reduce size, weight and power requirements enabling lower cost missions utilizing small spacecraft. Space Technology will also continue development of foundational technologies to support future outer planets icy moons missions with emphasis on landing and mobility, navigation and communications, radiation protection and accommodating power requirements.

In addition, Space Technology has developed a diverse portfolio of early-stage research and technology creating a technology pipeline to solve the Agency and Nation's most difficult exploration challenges. Space Technology will continue to prioritize "tipping point" technologies and early-stage innovation with over 600 awards to small businesses, private innovators, and academia to spark new ideas for the benefit of U.S. aerospace and high tech industries. As efforts complete, appropriate technologies will be transferred and commercialized to benefit a wide range of users to ensure the full economic value and societal benefit of these innovations is realized.

## EXTENDING HUMAN PRESENCE INTO THE SOLAR SYSTEM: ENABLING MULTIPLE DESTINATIONS ON THE JOURNEY TO MARS

NASA is developing the capability for people to live and work safely beyond the Earth for extended periods in increasingly distant locations. In this new era, NASA is implementing a multiple destination exploration strategy, using a capability driven approach. This strategy leverages compelling near-term mission opportunities that enable incremental buildup of capabilities for more complex missions in the future, such as exploring Mars and its moons.

# BUDGET HIGHLIGHTS

The Exploration account develops systems and capabilities required for deep-space exploration. The FY 2017 budget request for Exploration is $3,336.9 million.

As NASA works to expand human exploration deeper into space, cis-lunar space will provide a location from which we can mount missions to the more distant reaches of space, including expeditions to Mars. The distance and duration of these future missions requires that crew and transportation systems be completely independent of Earth. Logistics, power and propulsion systems, human factors, habitat, and operations, all these factors must be capable of supporting the autonomous operations necessary to travel millions of miles and spend many months in space. Our strategy is to move from Earth-reliant systems and achieve Earth-independent exploration capability for human mission durations that enable us to reach Mars and other destinations in the solar system.

## LIVING AND WORKING IN SPACE

The Space Operations Account funds critical NASA capabilities that create pathways for discovery and human exploration of space. These capabilities include research on and operation of ISS, affordable and reliable launches of NASA science missions, and critical communication links to crewed and robotic spacecraft. In addition to supporting NASA's activities, Space Operations also provides a platform for research and space transportation for non-NASA users. The FY 2017 budget request for Space Operations is $5,075.8 million.

The ISS offers a unique platform for NASA and its international partners to learn how to live and work in space. Research, technology demonstrations, tests, and experiments on the ISS continue to advance the capabilities required for future long-duration missions. NASA is making technological advances aboard ISS in autonomous rendezvous and docking, advanced communications systems, human health and behavior in space, habitat, and space suit systems, as well as in basic research in biological and physical sciences. For example, NASA is capitalizing on the extraordinary opportunity to study identical twins during Scott Kelly's year-long stay aboard ISS. Scott Kelly and Mark Kelly are genetically almost the same; studying one astronaut on the Earth, while one remains in space provides an unprecedented comparison of the impact spaceflight has on humans.

NASA and the U.S. space transportation industry are well on the way to developing an affordable capability to carry crew to ISS by the end of 2017, bolstering American leadership while eliminating reliance on the Russian Soyuz to transport American astronauts. This competitive commercial approach, versus a traditional NASA-owned and operated system, allows the Agency to reduce costs, improve affordability and sustainability, and stimulate the private sector space industry.

## NASA'S UNIQUE ASSETS MADE AVAILABLE TO SUPPORT THE NATION'S STEM EFFORTS

NASA's education programs continue to share the excitement of the Agency's science and engineering missions with learners, educators, and the public. Investments in the NASA education programmatic accounts maintain the advancement of high-quality STEM education using NASA's unique capabilities and resources. NASA's unique capabilities, resources, and expertise continue to play a crucial role in advancing the STEM goals in the Administration's Five-Year Federal Strategic Plan on STEM Education.

# BUDGET HIGHLIGHTS

NASA education continues to refine its programmatic activities to fuel increased interest, participation, and learning in STEM. Hands-on challenges with NASA experts generate interest in high school and undergraduate STEM study, fostering student participation in aerospace or related STEM fields. NASA's STEM education programs provide opportunities for educators and learners of all ages. A variety of carefully developed activities serve middle school audiences; offer pre- and in-service educator professional development; and provide experiential opportunities for high school and undergraduate students.

NASA's education programs have the potential to inspire learners to pursue STEM study and careers by engaging them in the Agency's missions, fostering collaborative relationships between learners and the current NASA workforce, and offering experiential learning opportunities at Agency facilities. NASA education will continue to coordinate closely with other Federal agencies in pursuit of the Administration's STEM education goals. The FY 2017 budget request for Education is $100.1 million.

## MANAGING NASA'S PEOPLE AND CAPABILITIES TO SAFELY ACCOMPLISH OUR MISSION

NASA's Safety, Security, and Mission Services account funds the essential day-to-day technical and business operations required to conduct NASA's aeronautics and space activities. These mission support activities provide the proper services, tools, and equipment to complete essential tasks, protect and maintain the security and integrity of information and assets, and ensure that personnel work under safe and healthy conditions. Planning, operating, and sustaining this infrastructure and our essential services requires a number of critical institutional capabilities including management of: human capital; finance; information technology; infrastructure; acquisitions; security; real and personnel property; occupational health and safety; equal employment opportunity and diversity; small business programs; external relations; strategic internal and external communications; stakeholder engagement; and other essential corporate functions. In FY 2017, NASA will continue to provide strategic and operational planning and management over a wide range of functions and services to help NASA operate in a more efficient and sustainable manner. The FY 2017 budget request for Safety, Security, and Mission Services is $2,836.8 million.

The Construction and Environmental Compliance and Restoration account enables NASA to manage the Agency's facilities with a focus on reducing infrastructure, implementing efficiency and high performance upgrades, and prioritizing repairs to achieve the greatest return on investment. In FY 2017, NASA continues to consolidate facilities to achieve greater operational efficiency, replacing old, obsolete, costly facilities with fewer, high performance facilities. Institutional construction projects replace deficient and obsolete facilities and correct deficiencies to support core capabilities within a smaller, more efficient footprint. Programmatic construction of facilities projects provide the specialized technical facilities required by the missions. NASA will decommission and continue preparations to dispose of property and equipment no longer needed for missions. To protect human health and the environment, and to preserve natural resources for future missions, environmental compliance and restoration projects will clean up pollutants released into the environment during past NASA activities. The FY 2017 request for Construction and Environmental Compliance and Restoration is $419.8 million.

# NOTES ON THE BUDGET

## MANDATORY FUNDING

The President believes that arbitrary funding caps are harmful to the economy and the Nation. Although the recent Bipartisan Budget Act provided important relief from sequester cuts, the constrained top line for discretionary funding, especially in FY 2017, has made it difficult to appropriately fund important national priorities, including research and development. In the FY 2017 Budget, the President proposes fully-paid-for one-year mandatory funding to accelerate progress in Science, Aeronautics, Space Technology, and Exploration, as well as additional multi-year mandatory funding for Aeronautics to support research and development for low carbon emission aircraft, including associated transportation systems, as part of a multi-agency effort to enable a 21st century clean transportation system.

## NASA'S WORKFORCE

NASA's workforce continues to be one of its greatest assets for enabling missions in space and on Earth. The Agency remains committed to applying this asset to benefit society, address contemporary environmental and social issues, lead or participate in emerging technology opportunities, collaborate and strengthen the capabilities of commercial partners, and communicate the challenges and results of Agency programs and activities. The civil service staffing levels proposed in the FY 2017 budget support NASA's scientists, engineers, researchers, managers, technicians, and business operations workforce. It includes civil service personnel at NASA Centers, Headquarters, and NASA-operated facilities. The mix of skills and distribution of workforce across the Agency is, however, necessarily changing.

NASA will continue to explore opportunities across the Agency to insource work and find efficiencies in workforce productivity, especially in mission support functional areas. The Agency will apply the valued civil service workforce to priority mission work, adjusting the mix of skills where appropriate. Centers will explore cross-mission retraining opportunities for employees whenever possible, offer targeted buyouts in selected surplus skill areas, and continue to identify, recruit, and retain a multi-generational workforce of employees who possess skills critical to the Agency.

## AGENCY DIGITAL SERVICE TEAMS

The success rate of government digital services is improved when agencies have digital service experts on staff with modern design, software engineering, and product management skills. To ensure the agency can effectively build and deliver important digital services, the FY 2017 Budget includes funding for staffing costs for a Digital Service team. This team focuses on transforming the agency's digital services with the greatest impact to citizens and businesses so they are easier to use and more cost-effective to build and maintain.

These digital service experts bring private sector best practices in the disciplines of design, software engineering, and product management to bear on the agency's most important services. The positions are term-limited, to encourage a continuous influx of up-to-date design and technology skills into the agency. The digital service experts are recruited from among America's leading technology enterprises and startups, and join with the agency's top technical and policy leaders to deliver meaningful and lasting improvements to the services the agency provides to citizens and businesses. This small team of tech experts has worked to establish best practices and to recruit more highly skilled digital service experts and engineers into government.

# EXPLANATION OF BUDGET TABLES AND SCHEDULES

NASA presents the FY 2017 budget request in full-cost, where all project costs are allocated to the project, including labor funding for the Agency's civil service workforce. Note that budget figures in tables may not add because of rounding.

## OUTYEAR FUNDING ASSUMPTIONS

At this time, funding lines beyond FY 2017 should be considered notional.

## EXPLANATION OF FY 2015 AND FY 2016 BUDGET COLUMNS

### FY 2015 Column

The FY 2015 Actual column in budget tables is consistent with the approved Agency spending plan (i.e. operating plan) control figures at the time of the budget release. Budget structure and figures are adjusted for comparability to the FY 2017 request. See note below.

All FY 2015 budget figures represent appropriations reflect funding amounts specified in the September 2015 Operating Plan per P.L. 113-235.

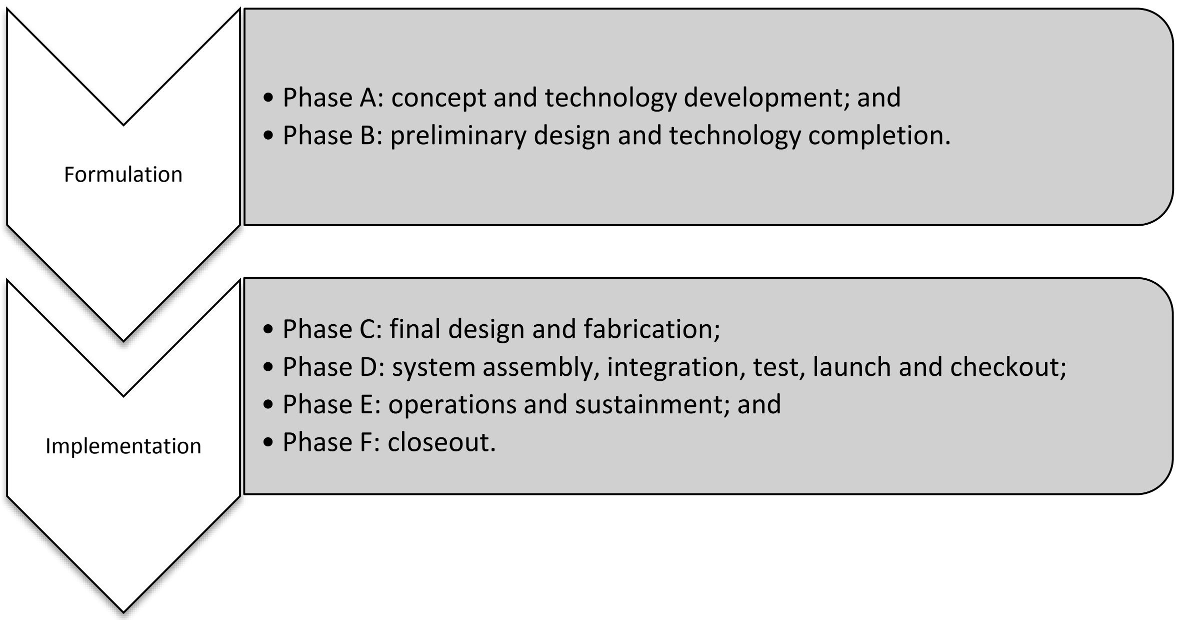
### FY 2016 Column

The FY 2016 Enacted column in budget tables displays appropriations enacted in the Consolidated Appropriations Act, 2016 (P.L. 114-113). As of budget release, an initial FY 2016 operating plan has not been adopted by Congress. As a result, budget tables show only accounts, themes, or programs where appropriations are called out in P.L. 114-113. Tables also show tentatively planned FY 2016 funding for projects in development (subject to change pending finalization of the FY 2016 initial operating plan). Budget structures and figures are adjusted for comparability to the FY 2017 budget structure. See note below.

# EXPLANATION OF BUDGET TABLES AND SCHEDULES

## EXPLANATION OF PROJECT SCHEDULE COMMITMENTS AND KEY MILESTONES

Programs and projects follow their appropriate life cycle. The life cycle is divided into phases. Transition from one phase to another requires management approval at Key Decision Points (KDPs). The phases in program and project life cycles include one or more life-cycle reviews, which are considered major milestone events.




A life-cycle review is designed to provide the program or project with an opportunity to ensure that it has completed the work of that phase and an independent assessment of a program's or project's technical and programmatic status and health. The final life-cycle review in a given life-cycle phase provides essential information for the KDP that marks the end of that life-cycle phase and transition to the next phase if successfully passed. As such, KDPs serve as gates through which programs and projects must pass to continue.

The KDP decision to authorize a program or project's transition to the next life-cycle phase is based on a number of factors, including technical maturity; continued relevance to Agency strategic goals; adequacy of cost and schedule estimates; associated probabilities of meeting those estimates (confidence levels); continued affordability with respect to the Agency's resources; maturity and the readiness to proceed to the next phase; and remaining program or project risk (safety, cost, schedule, technical, management, and programmatic). At the KDP, the key program or project cost, schedule, and content parameters that govern the remaining life-cycle activities are established.

For reference, a description of schedule commitments and milestones is listed below for projects in Formulation and Implementation. A list of common terms used in mission planning is also included.

# EXPLANATION OF BUDGET TABLES AND SCHEDULES

## Formulation

NASA places significant emphasis on project Formulation to ensure adequate preparation of project concepts and plans and mitigation of high-risk aspects of the project essential to position the project for the highest probability of mission success. During Formulation, the project explores the full range of implementation options, defines an affordable project concept to meet requirements, and develops needed technologies. The activities in these phases include developing the system architecture; completing mission and preliminary system designs; acquisition planning; conducting safety, technical, cost, and schedule risk trades; developing time-phased cost and schedule estimates and documenting the basis of these estimates; and preparing the Project Plan for Implementation.

| Formulation Milestone | Explanation |
|---|---|
| KDP-A | The lifecycle gate at which the decision authority determines the readiness of a program or project to transition into Phase A and authorizes Formulation of the project. Phase A is the first phase of Formulation and means that:<br>• The project addresses a critical NASA need;<br>• The proposed mission concept(s) is feasible;<br>• The associated planning is sufficiently mature to begin activities defined for formulation; and<br>• The mission can likely be achieved as conceived. |
| System Requirements Review (SRR) | The lifecycle review in which the decision authority evaluates whether the functional and performance requirements defined for the system are responsive to the program's requirements on the project and represent achievable capabilities |
| System Definition Review or Mission Definition Review | The lifecycle review in which the decision authority evaluates the credibility and responsiveness of the proposed mission/system architecture to the program requirements and constraints on the project, including available resources, and determines whether the maturity of the project's mission/system definition and associated plans are sufficient to begin the next phase, Phase B. |
| KDP-B | The lifecycle gate at which the decision authority determines the readiness of a program or project to transition from Phase A to Phase B. Phase B is the second phase of Formulation and means that:<br>• The proposed mission/system architecture is credible and responsive to program requirements and constraints, including resources;<br>• The maturity of the project's mission/system definition and associated plans is sufficient to begin Phase B; and<br>• The mission can likely be achieved within available resources with acceptable risk. |
| Preliminary Design Review (PDR) | The lifecycle review in which the decision authority evaluates the completeness/consistency of the planning, technical, cost, and schedule baselines developed during Formulation. This review also assesses compliance of the preliminary design with applicable requirements and determines if the project is sufficiently mature to begin Phase C. |

## Implementation

Implementation occurs when Agency management establishes baseline cost and schedule commitments for projects at KDP-C. The projects maintain the baseline commitment through the end of the mission. Projects are baselined for cost, schedule, and programmatic and technical parameters. Under Implementation, projects are able to execute approved plans development and operations.

| Implementation Milestone | Explanation |
|---|---|
| KDP-C | The lifecycle gate at which the decision authority determines the readiness of a program or project to begin the first stage of development and transition to Phase C and authorizes the Implementation of the project. Phase C is first stage of development and means that:<br>• The project's planning, technical, cost, and schedule baselines developed during Formulation are complete and consistent;<br>• The preliminary design complies with mission requirements;<br>• The project is sufficiently mature to begin Phase C; and<br>• The cost and schedule are adequate to enable mission success with acceptable risk. |
| Critical Design Review (CDR) | The lifecycle review in which the decision authority evaluates the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk within defined project constraints, including available resources. This review also determines if the design is appropriately mature to continue with the final design and fabrication phase. |
| System Integration Review (SIR) | The lifecycle review in which the decision authority evaluates the readiness of the project and associated supporting infrastructure to begin system assembly, integration, and test. The lifecycle review also evaluates whether the remaining project development can be completed within available resources, and determine if the project is sufficiently mature to begin Phase D. |
| KDP-D | The lifecycle gate at which the decision authority determines the readiness of a project to continue in Implementation and transition from Phase C to Phase D. Phase D is a second phase in Implementation; the project continues in development and means that:<br>• The project is still on plan;<br>• The risk is commensurate with the project's payload classification; and<br>• The project is ready for assembly, integration and test with acceptable risk within its Agency baseline commitment. |
| Launch Readiness Date (LRD) | The date at which the project and its ground, hardware, and software systems are ready for launch. |

# EXPLANATION OF BUDGET TABLES AND SCHEDULES

## Other Common Terms for Mission Planning

| Term | Definition |
|---|---|
| Decision Authority | The individual authorized by the Agency to make important decisions on programs and projects under their authority. |
| Formulation Authorization Document | The document that authorizes the formulation of a program whose goals will fulfill part of the Agency's Strategic Plan and Mission Directorate strategies. This document establishes the expectations and constraints for activity in the Formulation phase. |
| Key Decision Point (KDP) | The lifecycle gate at which the decision authority determines the readiness of a program or project to progress to the next phase of the life cycle. The KDP also establishes the content, cost, and schedule commitments for the ensuing phase(s). |
| Launch Manifest | This list that NASA publishes (the "NASA Flight Planning Board launch manifest") periodically, which includes the expected launch dates for NASA missions. The launch dates in the manifest are the desired launch dates approved by the NASA Flight Planning Board, and are not typically the same as the Agency Baseline Commitment schedule dates. A launch manifest is a dynamic schedule that is affected by real world operational activities conducted by NASA and multiple other entities. It reflects the results of a complex process that requires the coordination and cooperation by multiple users for the use of launch range and launch contractor assets. Moreover, the launch dates are a mixture of "confirmed" range dates for missions launching within approximately six months, and contractual/planning dates for the missions beyond six months from launch. The NASA Flight Planning Board launch manifest date is typically earlier than the Agency Baseline Commitment schedule date to allow for the operationally driven delays to the launch schedule that may be outside of the project's control. |
| Operational Readiness Review | The lifecycle review in which the decision authority evaluates the readiness of the project, including its ground systems, personnel, procedures, and user documentation, to operate the flight system and associated ground system(s), in compliance with defined project requirements and constraints during the operations phase. |
| Mission Readiness Review or Flight Readiness Review (FRR) | The lifecycle review in which the decision authority evaluates the readiness of the project, ground systems, personnel and procedures for a safe and successful launch and flight/mission. |
| KDP-E | The lifecycle gate at which the decision authority determines the readiness of a project to continue in Implementation and transition from Phase D to Phase E. Phase E is a third phase in Implementation and means that the project and all supporting systems are ready for safe, successful launch and early operations with acceptable risk. |
| Decommissioning Review | The lifecycle review in which the decision authority evaluates the readiness of the project to conduct closeout activities. The review includes final delivery of all remaining project deliverables and safe decommissioning of space flight systems and other project assets. |
| KDP-F | The lifecycle gate at which the decision authority determines the readiness of the project's decommissioning. Passage through this gate means the project has met its program objectives and is ready for safe decommissioning of its assets and closeout of activities. Scientific data analysis may continue after this period. |

# EXPLANATION OF BUDGET TABLES AND SCHEDULES

For further details, go to:

- NASA Procedural Requirement 7102.5E NASA Space Flight Program and Project Management Requirements: http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7120&s=5E.
- NASA Procedural Requirement NPR 7123.1B - NASA Systems Engineering Processes and Requirements: http://nodis3.gsfc.nasa.gov/npg_img/N_PR_7123_001B_/N_PR_7123_001B_.pdf.
- NASA Launch Services Web site: http://www.nasa.gov/directorates/heo/launch_services/index.html.

# SCIENCE

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Earth Science | 1784.1 | -- | **2032.2** | 1989.5 | 2001.3 | 2020.9 | 2047.7 |
| Planetary Science | 1446.7 | -- | **1518.7** | 1439.7 | 1520.1 | 1575.5 | 1625.7 |
| Astrophysics | 730.7 | -- | **781.5** | 761.6 | 992.4 | 1118.6 | 1192.5 |
| James Webb Space Telescope | 645.4 | 620.0 | **569.4** | 533.7 | 304.6 | 197.2 | 149.8 |
| Heliophysics | 636.1 | -- | **698.7** | 684.0 | 698.3 | 714.8 | 723.9 |
| **Total Budget** | **5243.0** | **5589.5** | **5600.5** | **5408.5** | **5516.7** | **5627.0** | **5739.6** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

# SCIENCE

# SCIENCE

## Heliophysics

# SCIENCE

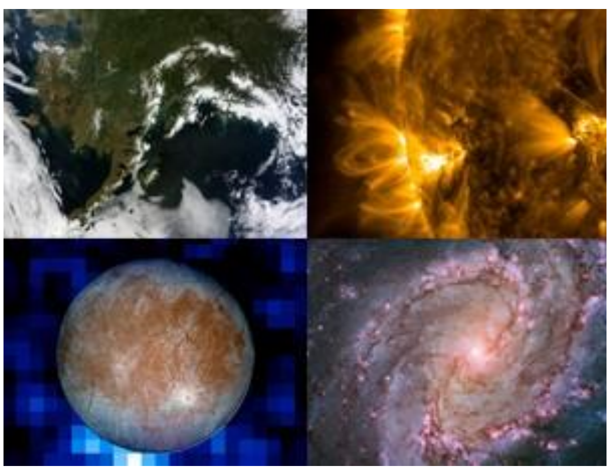
## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Earth Science | 1784.1 | -- | **2032.2** | 1989.5 | 2001.3 | 2020.9 | 2047.7 |
| Planetary Science | 1446.7 | -- | **1518.7** | 1439.7 | 1520.1 | 1575.5 | 1625.7 |
| Astrophysics | 730.7 | -- | **781.5** | 761.6 | 992.4 | 1118.6 | 1192.5 |
| James Webb Space Telescope | 645.4 | 620.0 | **569.4** | 533.7 | 304.6 | 197.2 | 149.8 |
| Heliophysics | 636.1 | -- | **698.7** | 684.0 | 698.3 | 714.8 | 723.9 |
| **Total Budget** | **5243.0** | **5589.5** | **5600.5** | **5408.5** | **5516.7** | **5627.0** | **5739.6** |
| Change from FY 2016 | | | **11.0** | | | | |
| Percentage change from FY 2016 | | | **0.2%** | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*



**From the vantage point of space, NASA captures breath-taking images of our world and the universe. These images advance our scientific understanding in a multitude of disciplines. They also have the power to inform policy, influence action, and inspire learning.**

NASA's Science Mission Directorate (SMD) conducts scientific exploration enabled by observatories and probes that view Earth from space, observe and visit other bodies in the solar system, and gaze out into the galaxy and beyond. NASA's science programs deliver answers to profound questions, such as:

- How and why are Earth's climate and the environment changing?
- How does the Sun vary; and how does it affect Earth and the rest of the solar system?
- How do planets and life originate?
- How does the universe work, and what are its origin and destiny?
- Are we alone?

NASA science programs address the need to understand our place in the universe, and provide information to policy makers who address issues affecting all life on the planet. NASA is also working to improve its operations and is increasingly launching its science missions on schedule and on budget. Our discoveries continue to rewrite textbooks; inspire children to pursue careers in science, technology, education, and mathematics (STEM); and demonstrate U.S. leadership worldwide.

# SCIENCE

NASA uses the recommendations of the National Academies' decadal surveys as an important input in planning the future of its science programs. For over 30 years, decadal surveys have proven vital in establishing a broad consensus within the national science community on the state of science, the highest priority science questions we can address, and actions we can take to address those priority science questions. NASA uses these recommendations to prioritize future flight missions, including space observatories and probes, as well as technology development and proposals for theoretical and suborbital supporting research. In that process, NASA must also adapt the science-based decadal survey recommendations to actual budgets, existing technological capabilities, national policy, partnership opportunities, and other programmatic factors. Assessments of how this budget request supports the recommendations of the most recent decadal surveys are included below.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| | Actual | Enacted | Request | Notional | | | |
|---|---|---|---|---|---|---|---|
| **Mandatory Funding (in $ millions)** | **FY 2015** | **FY 2016** | **FY 2017** | **FY 2018** | **FY 2019** | **FY 2020** | **FY 2021** |
| **Astrophysics Decadal Strategic Mission (WFIRST)** | -- | -- | **76.0** | -- | -- | -- | -- |
| **New Frontiers** | | | **40.0** | | | | |
| **Jupiter Europa** | | | **33.0** | | | | |
| **Small Satellite Constellation Initiative** | | | **30.0** | | | | |
| **Mars Exploration** | | | **29.0** | | | | |
| **Planetary Science Advanced Technology** | | | **10.0** | | | | |
| **CubeSats** | | | **10.0** | | | | |
| **Heliophysics Support for Space Weather Action Plan** | | | **10.0** | | | | |
| **Earth Science Research** | | | **30.0** | | | | |
| **Planetary Science Research** | | | **16.0** | | | | |
| **Astrophysics Research** | | | **9.0** | | | | |
| **Heliophysics Research** | | | **5.0** | | | | |

# SCIENCE

Science is supported with $298 million of mandatory funding, as indicated in the summary table above. This mandatory funding will allow NASA to:

- Sustain support for the Wide-Field Infrared Survey Telescope (WFIRST), which formally enters formulation in FY 2016;
- Move out aggressively with the next New Frontiers mission selection, and continue operating the Juno and New Horizons missions;
- Continue formulation of the Jupiter Europa mission;
- Increase the capabilities and uses of multi-spacecraft constellations of small scientific satellites;
- Continue operations of the Mars Opportunity, Mars Odyssey, and Mars Express missions;
- Accelerate technology development of future power systems and other areas important for future planetary exploration;
- Triple funding for the CubeSat project to enable highly ranked small satellite proposals addressing all SMD science disciplines;
- Increase Heliophysics research and planning in support of the Administration's Space Weather Strategy and Action Plan; and
- Augment Earth science and space science research programs to increase the science return from spaceflight missions.

Within discretionary funding levels, the budget request for Earth Science includes no funding for a Thermal Infrared Free Flyer (TIRFF), but supports launch of Landsat 9 as early as 2021, as well as technology investments and detailed system engineering to support future land-imaging satellites.

The budget request for Planetary Science supports the new Agency Aeroscience Ground Test Capabilities project. This project, carried within the Mars Exploration Program, will sustain our Mars atmospheric entry, descent, and landing design capabilities for Mars 2020 and any subsequent landed missions.

## ACHIEVEMENTS IN FY 2015

### SCIENCE RESULTS

A steady pace of important science results continued in FY 2015. In Earth Science, a study reported that emissions of hydrofluorocarbons from developed countries are consistent with atmospheric measurements, and almost half of global emissions now originate from non-reporting countries. Meanwhile, NASA's Short-term Prediction Research and Transition (SPoRT) program continued to make significant progress in transitioning weather research products to the operational community. SPoRT collaborated with National Oceanic and Atmospheric Administration (NOAA) to assess a snowfall rate product that uses microwave data from the Suomi-National Polar-orbiting Partnership (Suomi-NPP) mission to estimate liquid-equivalent snowfall rates. Forecasters can then identify the areas of the heaviest snowfall during winter weather events, like the historic January 2015 Northeast blizzard.

In Planetary Science, the New Horizons probe, launched on January 19, 2006, lifted the veil on Pluto. In early 2015, the instruments began taking measurements and making the first maps of Pluto and its moons. On July 14, New Horizons performed the first-ever flyby of Pluto, zooming within 7,800 miles (12,500 kilometers) of its frigid surface. It made numerous observations, including close-up images in visible and near-infrared wavelengths depicting surface features as small as 200 feet across, and bringing a plethora of new discoveries. The spacecraft also completed the maneuvers required to fly by Kuiper Belt Object 2014MU69 in January 2019.

In Astrophysics, scientists using NASA's Hubble Space Telescope produced new global maps of Jupiter. These maps are first in a series of annual portraits of the solar system's outer planets from the Outer Planet Atmospheres Legacy program (OPAL). The Hubble observations confirm that the Great Red Spot, the weather system on planet Jupiter continues to shrink and become more circular. The collection of maps NASA will obtain over time will not only help scientists understand the atmospheres of our giant planets, but also the atmospheres of planets around other stars.

Heliophysics missions provided evidence for two physical mechanisms that could explain why the Sun's corona is over a thousand times hotter than its surface. Scientists combined data from NASA's Interface Region Imaging Spectrograph (IRIS) and the joint Japanese Aerospace Exploration Agency (JAXA)–NASA Hinode satellite to show how magnetic waves carry energy from the surface to filaments in the corona. In a separate study of hotter regions on the Sun, scientists used data from IRIS and NASA's Solar Dynamics Observatory (SDO) to reveal evidence for an alternative heating mechanism in which small events called nanoflares release magnetic energy. These new results show that coronal heating is more complex than originally thought, with the dominant mechanisms likely dependent on local conditions.

NASA highlights these and many other scientific results in the pages that follow.

## COST AND SCHEDULE PERFORMANCE

The majority of Science missions continue to demonstrate very good cost and schedule performance. The Soil Moisture Active/Passive (SMAP) launched on January 31, 2015, two months ahead of schedule and four percent under its development cost commitment. The Magnetospheric MultiScale (MMS) mission, launched on April 1, 2015, overran its development costs by about two percent, slightly better than estimated in last year's request.

Eight Science missions under development are holding to their original cost and schedule baseline estimates: ASTRO-H, Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer (OSIRIS-REx), Cyclone Global Navigation Satellite System (CYGNSS), Ionospheric Connection Explorer (ICON), Gravity Recovery and Climate Experiment Follow-On (GRACE-FO), Transiting Exoplanet Survey Satellite (TESS), Solar Probe Plus (SPP), and Solar Orbiter Collaboration (SOC).

Two small Science projects experienced minor cost and schedule overruns in 2015. The Stratospheric Aerosol and Gas Experiment III (SAGE-III) will be a few months late and a few percent over budget when launched to the International Space Station (ISS) in 2016. NASA's contribution to the European Space Agency (ESA)'s Euclid mission will also exceed its cost and schedule commitments.

On December 22, 2015, NASA announced the suspension of the planned March 2016 launch of the Interior Exploration using Seismic Investigations Geodesy and Heat Transport (InSight) mission to Mars. NASA will announce a decision on the future of the mission in the next few months. If NASA launches InSight at its next opportunity in 2018, it will exceed its original cost and schedule commitments.

The James Webb Space Telescope (Webb) and the Ice, Cloud, and land Elevation Satellite (ICESat)-2 experienced past cost and schedule growth, but experienced no growth in 2015.

# SCIENCE

## WORK IN PROGRESS IN FY 2016

NASA is operating over 55 Science missions with over 70 spacecraft, most of which involve collaboration with international partners or other U.S. agencies. Work on over 35 missions in formulation and development continues. Suborbital flights using aircraft, sounding rockets, and balloons are ongoing, as are more than 3,000 competitively selected research awards to scientists located at universities, NASA field Centers, and other government agencies.

Several major mission events are upcoming in 2016. JAXA plans to launch the ASTRO-H x-ray astronomy mission (with major NASA-provided components) in late January. NASA plans to deliver SAGE-III to the ISS in June. In July, five years after its launch, Juno will arrive at Jupiter and begin science observations. In September, the Cassini mission will begin to orbit between Saturn and its rings. OSIRIS-REx will launch in September or October, to begin its journey to the asteroid Bennu.

In September 2015, NASA selected five Discovery mission proposals for further study; in October 2016, NASA will select one or two of those missions for development. NASA will release several Announcements of Opportunity (AOs) for new missions later this fiscal year, including Heliophysics Explorers, Astrophysics Explorers, and Earth Venture (EV) Instruments.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA plans to launch CYGNSS in FY 2017, with the goal of making a fundamental improvement in hurricane forecasting. Two payloads will launch to the ISS: the Orbiting Carbon Observatory 3 (OCO-3) mission to measure atmospheric carbon dioxide, and the Neutron star Interior Composition ExploreR (NICER), dedicated to the study of the extraordinary gravitational, electromagnetic, and nuclear physics properties of neutron stars.

NASA will release AOs for the fifth Heliophysics Solar Terrestrial Probes mission, for the next New Frontiers mission, and for the third set of EV Suborbital instruments.

# Themes

## EARTH SCIENCE

From space, NASA satellites can view Earth as a planet and enable the study of it as a complex, dynamic system of diverse components: the oceans, atmosphere, continents, ice sheets, and life. The Nation's scientific community can thereby observe and track global-scale changes, connecting causes to effects. Scientists can study regional changes in their global context, as well as observe the role that human civilization plays as a force of change. Through partnerships with agencies that maintain forecasting and decision support systems, NASA improves national capabilities to predict climate, weather, and natural hazards; manage resources; and support the development of environmental policy.

The primary recommendations of the National Academies' 2007 Decadal Survey for Earth Science and Applications from Space (ESAS), which informed the 2010 Climate-Centric Architecture plan, were:

- Complete the ongoing program. All legacy Earth Science missions identified in the 2007 ESAS Decadal [Jason-2 (2008), OCO (2009, 2014), Glory (2011), Aquarius (2011), Suomi-NPP (2011), Landsat 8 (2013)] have been developed and launched. OCO-1 and Glory suffered launch vehicle failures. OCO-2 was then developed and successfully launched. The FY 2017 budget fully funds operations and science exploitation of these on-orbit missions.

- Continue the balance between flight and non-flight activities. The FY 2017 request fully supports this recommendation.
- Increase the scope and fraction of the Earth Science Technology program. The FY 2017 request fully supports this recommendation, in part through funding for the In-Space Validation of Earth Science Technologies (InVEST) CubeSat-based program.
- Establish a robust program of competed Venture-class missions. The FY 2017 budget request fully supports this recommendation. It funds all EV missions selected under previous solicitations. It also fully funds the planned future solicitations in all three strands on schedule (4-year cadence for EV-Suborbital and EV-Mission, 18-month cadence for EV-Instrument).
- Aggressively develop a number of future strategic missions. The 2007 ESAS Decadal identified four systematic Tier-1 missions [Soil Moisture Active Passive, ICESat-2, Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI), Climate Absolute Radiance and Refractivity Observatory (CLARREO)] for launch by 2013. The Decadal also identified five Tier-2 missions [Hyperspectral Infrared Image (HyspIRI), Surface Water Ocean Topography (SWOT), GEOstationary Coastal and Air Pollution Events (GEO-CAPE), Active Sensing of CO2 Emissions over Nights, Days, and Seasons (ASCENDS), and Aerosol-Cloud-Ecosystem (ACE)] by 2016. Those Decadal recommendations assumed unrealistically low mission costs and overly optimistic budgets, rendering the target launch dates unachievable. NASA launched the Soil Moisture Active Passive mission in January 2015. The FY 2017 budget request fully funds ICESat-2 (2018), the radar portion of DESDynI (NISAR, 2022), a Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) mission (PACE, 2022) and technology demonstration instruments for risk reduction for CLARREO (for launch to the ISS in 2019). The request also funds completion of high-priority, Decadal-identified, continuity missions: Stratospheric Aerosol and Gas Experiment (SAGE)-III (2016), Landsat-9 (2021), GRACE-FO (2018, deferred to Tier-3 in the Decadal), and Surface Water Ocean Topography (2020). These dates are consistent with the latest Key Decision Point decisions and Agency commitments.

NASA asks the Earth Science Subcommittee of the NASA Advisory Committee for input regarding budget priorities, to ensure that our proposed programs maximize scientific productivity, within the general framework established by the National Academies.

## PLANETARY SCIENCE

To answer questions about the solar system and the origins of life, NASA sends robotic space probes to the Moon, other planets and their moons, asteroids and comets, and the icy bodies beyond Neptune. NASA is in the midst of a sustained investigation of Mars, launching a series of orbiters, landers, and rovers, with the long-term goal of eventual human exploration. NASA is planning the next Mars rover, which will launch in 2020 and address key questions about the potential for life on Mars. NASA is completing humankind’s first reconnaissance of the solar system following the recent fly-by of Pluto, operating spacecraft at Saturn and the largest asteroid Ceres, returning to Jupiter, and preparing a mission that will return to Earth samples from a near-Earth asteroid.

# SCIENCE

The primary recommendations of the National Academies' 2012 Decadal Survey for Planetary Science were:

1. Continue Discovery solicitations, with the cost cap adjusted for inflation and a 24-month cadence. NASA adjusted the cost cap of the latest AO per the Decadal recommendation. The out-year budget supports an approximate 24-to-36-month cadence for new mission competitions.
2. Continue New Frontiers with a $1 billion cost cap, and select two new missions by 2022. This budget supports a new AO in 2017 with selection by the end of 2018.
3. Begin the two highest priority flagships: a Mars Astrobiology Explorer-Cacher and a Europa mission. This budget supports a Mars 2020 rover mission that will address the highest priority Mars science objectives recommended by the Planetary Decadal Survey and continues formulation of a Europa mission project, for launch in the late 2020s.
4. Continue missions in development and flight, subject to senior review. This budget fully supports all missions selected for development, all missions in prime operations, and all extended missions ranked highly in the latest senior review.
5. Increase research and analysis (R&A) spending by 5 percent above the FY 2011 budget level, and then 1.5 percent above inflation thereafter. The total R&A budget in FY 2011 was $208 million. This budget funds R&A programs at $223 million in FY 2017.
6. Increase Planetary Technology spending to six to eight percent of the total division budget, including completion of the advanced Stirling radioisotope generators. This budget funds technology at roughly four percent, less than the Decadal Survey recommendation due to the competing funding needs of spaceflight missions, including two flagship missions. NASA is investigating the state of Stirling technologies across industry and defining requirements for future Stirling development projects.

The proposed budget deviates from Decadal Survey recommendations due to overly optimistic Decadal assumptions regarding future budgets. NASA has made adjustments across the portfolio to ensure balance accordingly.

NASA asks the Planetary Science Subcommittee of the NASA Advisory Committee for input regarding budget priorities, to ensure that our proposed programs maximize scientific productivity, within the general framework established by the National Academies.

## ASTROPHYSICS

The theories of the past century about the physical universe related to the Big Bang, black holes, and dark matter and dark energy challenge scientists and NASA to use observations from space to test conventional understanding of fundamental physics. Having measured the age of the universe, the scientific community now seeks to explore further extremes: its birth, the edges of space and time near black holes, and the mysterious dark energy filling the entire universe. Scientists have recently developed astronomical instrumentation sensitive enough to detect planets around other stars. With hundreds of extrasolar planets now known, scientists are using current NASA missions in conjunction with ground-based telescopes to seek Earth-like planets in other solar systems.

The 2010 Decadal Survey in Astronomy and Astrophysics, New Worlds, New Horizons (Astro2010) in Astronomy and Astrophysics, recommended a coordinated program of research, technology development, ground-based facilities, and space-based missions for implementation during 2012–2021. The primary recommendations were:

- Complete the ongoing program. The Astro2010 Decadal Survey assumed launch of Webb in 2014; full operations of the Stratospheric Observatory for Infrared Astronomy (SOFIA) airborne observatory in 2012; and completion of three Explorer missions: the Nuclear Spectroscopic Telescope Array (NuSTAR) in 2012, the Gravity and Extreme Magnetism (GEMS) Explorer in 2014, and the U.S. contribution to the Japanese ASTRO-H mission in 2014. This budget fully supports launch of Webb in 2018, delivery of the ASTRO-H instrument to Japan for launch in 2016, and continued operations by SOFIA (fully operational in 2014) and NuSTAR (launched in 2012). NASA halted development of GEMS in 2012 due to cost overruns.
- Support the ongoing core research program to ensure a balanced program that optimizes overall scientific return. This budget fully supports the ongoing core research program and maintains a balanced program of large missions, small missions, research and analysis, suborbital projects, and technology development addressing the highest priorities in cosmic origins, exoplanet exploration, and physics of the cosmos.
- Launch WFIRST by 2020. This budget supports formulation of a 2.4-meter version of WFIRST, incorporating the Astrophysics Focused Telescope Assets (AFTA) and potentially a coronagraph. This request supports the start of Phase A formulation activities, and launch as early as 2025.
- Augment the Astrophysics Explorers Program to support the selection of four missions and four smaller missions of opportunity each decade. This budget fully supports the recommended cadence of new Astrophysics Explorers missions, with AOs in 2014, 2016/2017, and 2019.
- Launch the Laser Interferometer Space Antenna (LISA) by 2025. This budget supports studies leading toward a potential contribution to an ESA-led gravitational wave observatory for launch in 2034.
- Invest in Technology leading toward an international X-ray observatory in the 2020s. This budget supports a U.S. contribution to the ESA-led Athena advanced X-ray observatory for launch in 2028.
- Invest in a New Worlds technology development and precursor science program for a 2020s mission to image habitable rocky planets. This budget supports the development of technology and conduct of precursor science required for a potential future mission to directly image and characterize habitable rocky exoplanets.
- Invest in technology development and precursor science for a 2020s mission to probe the epoch of inflation. This budget supports the development of technology and conduct of precursor science required for a potential future mission to probe the epoch of inflation.
- Increase funding for several targeted areas of supporting research and technology. This budget supports increased funding for research and analysis including recommended investments in intermediate technology development, theoretical and computational networks, suborbital programs, laboratory astrophysics, and technology for future ultraviolet/visible space telescopes.

NASA has and is continuing to address many of the Decadal Survey recommendations, though in some cases at a slower pace. Adjustments to the Decadal Survey recommendations are primarily due to overly optimistic Decadal assumptions regarding future budgets and challenges and delays to programs such as Webb. Other factors that could not be anticipated by the Decadal Survey include the availability of the AFTA, changing international partnership opportunities, emerging technologies that have changed what can be accomplished, and advances in our scientific understanding of the universe.

# SCIENCE

NASA asks the Astrophysics Subcommittee of the NASA Advisory Council for input regarding budget priorities, to ensure that our proposed programs maximize scientific productivity, within the general framework established by the National Academies.

## JAMES WEBB SPACE TELESCOPE (WEBB)

Webb is a large, space-based astronomical observatory. The mission is a successor to the Hubble Space Telescope, extending beyond Hubble's discoveries by looking into the infrared spectrum, where the highly red-shifted early universe is observable, where relatively cool objects like protostars and protoplanetary disks strongly emit infrared light, and where dust obscures shorter wavelengths. Webb is progressing well towards its scheduled launch in October 2018, within the cost and schedule baseline NASA established in 2011.

## HELIOPHYSICS

The Sun, a typical small star midway through its life, governs the solar system. The Sun wields its influence through its gravity, radiation, solar wind, and magnetic fields, all of which interact with the gravity, fields, and atmospheres of Earth to produce space weather, which can affect human technological infrastructure and activities. Using a fleet of sensors on various spacecraft in Earth orbit and throughout the solar system, NASA seeks to understand how and why the Sun varies, how Earth responds to the Sun, and how human activities are affected. The science of heliophysics enables the predictions necessary to safeguard life and society on Earth and the outward journeys of human and robotic explorers.

The primary recommendations of the National Academies' 2013 Decadal Survey for Heliophysics were:

Maintain and complete the current program. The Decadal assumed launch of Van Allen Probes by 2012, IRIS by 2013, MMS by 2014, SOC by 2017, SPP by 2018, and continued current funding of the Research program. Van Allen, IRIS, and MMS have launched, and SOC and SPP are currently on schedule. This budget fully supports those missions.

Implement the DRIVE (Diversify, Realize, Integrate, Venture, Educate) initiative, resulting in an increase of the competed research program from 10 percent to about 15 percent of the budget request. This budget supports a gradual increase with a goal of fully implementing DRIVE by the end of the decade.

Accelerate and expand the Heliophysics Explorer Program, resulting in an increase to the cadence of competed missions to one launch every 2-3 years, starting in roughly 2018. This budget supports the launch of ICON and GOLD in 2017/2018 respectively, six years after the previous Explorer launch. The notional out-year budgets, if realized, would support the next launch around 2022.

Restructure Solar Terrestrial Probes (STP) as a moderate scale principal investigator-led flight program, and implement three mid-scale missions with an eventual recommended 4-year cadence. This budget assumes an AO no earlier than 2017 for a launch in about 2023. The procurement strategy (principle investigator-led versus Center led) for future STP strategic missions is not budget dependent.

Implement a large Living with a Star (LWS) mission to study Global Dynamic Coupling with a launch in 2024. This budget does not support this mission as described in the Decadal Survey.

The FY 2017 budget deviations from Decadal Survey recommendations are due to overly optimistic Decadal assumptions regarding future budgets. The Heliophysics Decadal Survey provided specific decision rules for prioritizing the recommendations if the enacted budgets did not meet assumptions. The projects supported within this budget request follow those decision rules. NASA asks the Heliophysics Subcommittee of the NASA Advisory Committee for input regarding budget priorities to ensure that our proposed programs maximize scientific productivity within the general framework established by the National Academies.

The decadal survey went beyond its Heliophysics science recommendations and made recommendations related to space weather applications, addressed collectively to the relevant government agencies. NASA will continue collaborating with other agencies to improve space weather observation and forecasting capabilities.

# EARTH SCIENCE

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Earth Science Research | 453.2 | -- | **501.7** | 472.9 | 461.3 | 475.9 | 484.2 |
| Earth Systematic Missions | 827.3 | -- | **933.0** | 965.5 | 1021.3 | 1005.0 | 1000.1 |
| Earth System Science Pathfinder | 223.8 | -- | **296.0** | 248.6 | 216.7 | 227.8 | 245.1 |
| Earth Science Multi-Mission Operations | 179.7 | -- | **191.8** | 194.3 | 193.6 | 197.9 | 202.6 |
| Earth Science Technology | 59.7 | -- | **61.4** | 60.4 | 59.7 | 62.7 | 63.7 |
| Applied Sciences | 40.4 | -- | **48.2** | 47.9 | 48.7 | 51.5 | 52.0 |
| **Total Budget** | **1784.1** | **--** | **2032.2** | **1989.5** | **2001.3** | **2020.9** | **2047.7** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

## Earth Science

# EARTH SCIENCE RESEARCH

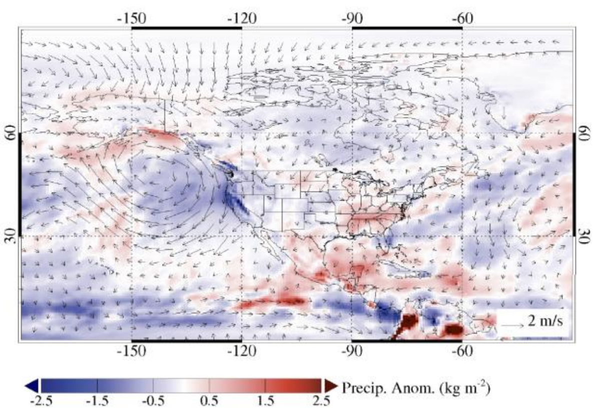
## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Earth Science Research and Analysis | 331.6 | -- | **360.7** | 322.6 | 312.4 | 322.4 | 326.7 |
| Computing and Management | 121.7 | -- | **141.0** | 150.3 | 148.8 | 153.5 | 157.5 |
| **Total Budget** | **453.2** | -- | **501.7** | **472.9** | **461.3** | **475.9** | **484.2** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*




**NASA scientists used modern satellite and reanalysis data to reassess certain aspects of the precipitation climate in California from the past three decades. California has a well-pronounced rain season that peaks in December-February. However, the 95percent confidence interval around the climatological precipitation during these months imply that deviations on the order of 60 percent of the expected amounts are very likely during the most important period of the rain season. While these positive and negative anomalies alternate almost every year and tend to cancel each other, severe multi-year declines of precipitation in California seem to appear on decadal scales. The 1986-1994 decline of precipitation was similar to the current one that started in 2011, and is apparent in the reanalysis data. In terms of accumulated deficits of precipitation, that episode was no less severe than the current one.**

NASA's Earth Science Research program develops a scientific understanding of Earth and its response to natural or human-induced changes. Earth is a system, like the human body, comprised of diverse components interacting in complex ways. Understanding Earth's atmosphere, crust, water, ice, and life as a single, connected system is necessary in order to improve our predictions of climate, weather, and natural hazards.

The Earth Science Research program addresses complex, interdisciplinary Earth science problems in pursuit of a comprehensive understanding of the Earth system. This strategy involves six interdisciplinary and interrelated science focus areas, including:

- Climate Variability and Change: understanding the roles of ocean, atmosphere, land, and ice in the climate system and improving our ability to predict future changes;
- Atmospheric Composition: understanding and improving predictive capability for changes in the ozone layer, Earth's radiation budget, and air quality associated with changes in atmospheric composition;
- Carbon Cycle and Ecosystems: quantifying, understanding, and predicting changes in Earth's ecosystems and biogeochemical cycles, including the global carbon cycle, land cover, and biodiversity;

# EARTH SCIENCE RESEARCH

- Water and Energy Cycle: quantifying the key reservoirs and fluxes in the global water cycle, assessing water cycle change, and water quality;
- Weather: enabling improved predictive capability for weather and extreme weather events; and
- Earth Surface and Interior: characterizing the dynamics of the Earth's surface and interior and forming the scientific basis for the assessment and mitigation of natural hazards and response to rare and extreme events.

NASA's Earth Science Research program pioneers the use of both space-borne and aircraft measurements in all of these areas. NASA's Earth Science Research program is critical to the advancement of the interagency U.S. Global Change Research Program (USGCRP). NASA's Earth Science Research program also makes extensive contributions to international science programs, such as the World Climate Research Programme.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| | Actual | Enacted | Request | Notional | | | |
|---|---|---|---|---|---|---|---|
| **Budget Authority (in $ millions)** | **FY 2015** | **FY 2016** | **FY 2017** | **FY 2018** | **FY 2019** | **FY 2020** | **FY 2021** |
| Mandatory Budget Authority | -- | -- | 30.0 | -- | -- | -- | -- |

Earth Science Research and Analysis is supported with $30 million of mandatory funding, which will enhance the scientific return from on-going and completed satellite missions.

## ACHIEVEMENTS IN FY 2015

The Earth Science Subcommittee of the NASA Advisory Council Science Committee determined in August 2015 that NASA remained on track towards the achievement of its annual research goals, relevant to the six science focus areas described in the previous section. Examples of the scientific progress reported in FY 2015 follow.

A study reported that global emissions of hydrofluorocarbons (HFCs) are roughly twice that reported to the United Nations (UN) by developed countries, with the rest most likely originating from non-reporting developing countries. HFCs are powerful greenhouse gases, and many countries report HFC emissions to the UN through the Montreal Protocol, which does not yet require reporting or regulate HFCs because they are not ozone depleting substances. Many countries, led by the U.S., have been pushing to have them included and regulated through the Montreal Protocol for some time now, but the UN has not finalized agreements.

A recent study made use of combined ground-based, in-situ, and satellite observations to find that, from 1990 to 2007, there has been an increase in tropospheric ozone over southern Africa. Another study reported a decrease in the spatial distribution of tropospheric carbon monoxide, using observations from the Measurements Of Pollution In The Troposphere (MOPITT) instrument and in-situ measurements from 2002 to 2011.

# EARTH SCIENCE RESEARCH

NASA's Short-term Prediction Research and Transition (SPoRT) program continued to make significant progress in transitioning weather research products to the operational community. SPoRT collaborated with the National Oceanic and Atmospheric Administration (NOAA) to assess a snowfall rate product that includes data from the Suomi National Polar-Orbiting Partnership (Suomi NPP) Advanced Technology Microwave Sounder instrument. The product uses information in microwave channels to estimate liquid-equivalent snowfall rates, which forecasters can use to identify the areas of the heaviest snowfall during winter weather events, such as the historic January 2015 U.S. Northeast blizzard.

A recent study developed a prototype online extreme-precipitation monitoring system, using data from the Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA) near-real-time precipitation product. The system provides additional information for ongoing precipitation events based on local climatology, which the general public and decision makers can use for various hazard-management applications.

Researchers have already used the first year of Global Precipitation Measurement (GPM) mission data to classify the global behavior of precipitation features. The study asserted that while extreme precipitation systems are rare, they contribute significantly to the global precipitation and their impacts should be included in global climate models to describe the global water cycle correctly.

Using satellite-remote sensing products, researchers found that vegetation cover was more important than weather in controlling the severity of fires in central Idaho and western Montana forests. In addition, a study showed that between 1991 and 2010, harvests, fires, pests, and pathogens disturbed 13 percent of the forests in western Oregon. Scientists also found that, because of differences in forest type and plant community structure, boreal forests in North America were more vulnerable to high intensity crown fires than those in Eurasia.

Investigators analyzed the relationship between the progress of accumulated springtime temperatures and satellite observations of landscape greenness across the U.S. Great Plains during 2002–2012. Results revealed that urban intensity, as measured by the proportion of impervious surface area, influences the seasonal progression of landscape greenness differently, depending on regional climate. Also in the area of urban growth, the Po Plain Experiment is a research project on mega-urban changes and associated impacts on the local environment. Innovative data processing and use of Quick Scatterometer (QuikSCAT) satellite data allowed scientists to successfully develop a spatially and temporally consistent dataset delineating urban extension.

A daylong symposium providing decision makers with insight into state and regional terrestrial biomass estimates, as well as Indonesian, Mexican, and African carbon dynamics, preceded the Carbon Monitoring System science team meeting. Accomplishments include globally gridded land use and land cover projections to 2100, using remote sensing alongside land use allocations from a socio-economic model.

NASA's Land Data Assimilation System (LDAS) and Land Information System (LIS) tools continue to improve; NASA upgraded LIS to assimilate remotely sensed soil moisture from the Soil Moisture Active Passive (SMAP) mission and terrestrial water storage from the Gravity Recovery and Climate Experiment (GRACE). Upgrades also enabled improved model forcing with increased spatial resolution, the expansion of the LDAS domain to all of North America, and the reduction of data lag to near zero. The team held tutorials on the software to transition it into National Centers for Environmental Prediction operations. Scientists created a National Climate Assessment version of LDAS as an end-to-end enabling tool for sustained evaluation and dissemination of terrestrial hydrologic variables.

A study examined the creation of a North American river width database that contains over 240,000 kilometers of rivers wider than 30 meters. Investigators argue that North American river surface area is underestimated by 20 percent, which could greatly affect estimates of river discharge and carbon fluxes from rivers to the atmosphere. The team is working on a similar global river width database for use by Surface Water Ocean Topography (SWOT) algorithm developers. Another study detailed a method to estimate water depth in flooded forests and applied it to the Congo Basin. This new approach offers a method to calibrate and validate multiple aspects of two-dimensional hydrodynamic modeling. Investigators can apply this approach to other regions and it should serve as a useful pre-launch virtual mission study for SWOT.

A study of sea level rise using Jason-2 altimetry, GRACE, and the Argo array of more than 3,000 free-drifting floats concluded that the deep ocean has not warmed enough to account for the hiatus in air temperature increase over the past decade. Thus, researchers conclude that the added heat is stored in the upper layers of the ocean. Another study found that the partitioning of northern and southern hemispheric simulated sea surface height changes from climate models are consistent with precise altimeter observations, but inconsistent with in-situ estimates of ocean heat content between 1970 and 2004.

The picture of the Greenland Ice Sheet continued to develop, with more information than ever about its surface and the bedrock beneath it. Researchers compiled aircraft and satellite laser altimetry measurements from 1993 to 2012 to reconstruct records of ice thickness change at 100,000 sites in Greenland. They also constructed a comprehensive deep stratigraphy of the Greenland Ice Sheet from airborne ice-penetrating radar data collected between 1993 and 2013.

NASA investigators used data from the GRACE satellite mission to measure and model the large gravity changes after the 2012 Indian Ocean earthquake sequence, showing that GRACE data are suitable for analyzing some earthquakes as small as magnitude 8.2. Researchers also used numerical simulations of earthquake fault systems and the Virtual California model to estimate gravity changes.

The National Science Foundation (NSF) and NASA-funded Plains Elevated Convection at Night field campaign was staged in the central U.S. from June 1 to July 15, 2015. In addition to airborne instruments, three ground instruments from NASA/Goddard Space Flight Center (GSFC) participated in the experiment: X-badger radar, GLOW direct detection wind lidar, and the ALVICE Raman lidar. The campaign focused on initiation mechanisms for nighttime convection.

Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) is an L-band repeat-pass interferometric synthetic aperture radar that serves as a technology test bed for the NASA-ISRO Synthetic Aperture Radar (NISAR) mission and provision of science data. UAVSAR continued twice-annual coverage of much of the San Andreas Fault, continued monitoring of levees in the Sacramento Delta in collaboration with the California Department of Water Resources, and continued studies of landslides in Colorado and Alaska and deformation in the Mississippi Delta. A major campaign to South and Central America in March and April 2015 continued studies of volcanic processes and provided calibration/validation support to the SMAP mission with sites in Argentina. A campaign in May and June 2015 studied short-term variations in glacial velocity fields in Iceland and participated in a joint study with Norway to characterize oil spills. In addition, UAVSAR began support of permafrost studies in

Alaska in conjunction with the P-band Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) instrument.

## WORK IN PROGRESS IN FY 2016

Operation IceBridge continues as the largest airborne survey of the Earth's polar ice ever flown to provide data continuity between the loss of the Ice, Cloud, and land Elevation Satellite (ICESat)-1 satellite and the launch of ICESat-2. It is yielding a three-dimensional view of the Arctic and Antarctic ice sheets, ice shelves, and sea ice. These flights provide a yearly, multi-instrument look at the behavior of the polar ice sheets to determine their contributions to current and future global sea level rise, and help us understand the changes in sea ice cover and the Earth system.

NASA and the National Institute of Environmental Research of Korea are preparing for the Korea-United States Air Quality Field Study in May and June of 2016. The study will integrate ground, airborne, and satellite observations with modeling tools in preparation for future geostationary missions by each country. The study will involve at least four research aircraft, two research vessels, and more than ten ground sites, measuring and monitoring trace gases and aerosols both upwind of the Asian continent and downwind of the Korean peninsula. The outcomes of this field study will improve our ability to measure atmospheric composition from space and develop a better understanding of the changes in pollution emissions from Asia.

NASA will begin fieldwork and related research for the Arctic – Boreal Vulnerability Experiment (ABoVE) in Alaska and northwestern Canada to examine the vulnerability and resilience of northern ecosystems to a changing environment. ABoVE will address the dynamics of fauna, vegetation structure and function, fire dynamics, carbon dynamics, permafrost and hydrology, and predictive model development and testing. Two hundred and thirty-two investigators will participate.

Scientists will conduct a joint ESA-NASA airborne campaign (AfriSAR) in Gabon, Africa during winter 2016 to assess the use of P-band, L-band radar and lidar remote sensing to optimize algorithms used to help estimate biomass and related quantities for this major tropical forest region. This work is pertinent to the development of future spaceborne sensors planned by NASA and ESA.

During FY 2016, NASA will initiate research on the formation of tornadoes. The research was selected after Research Opportunities in Space and Earth Sciences (ROSES) 2015 competition, the first ever solicitation on tornado genesis research.

In collaboration with ESA, NASA will plan the development and implementation of the follow on assessment to the Ice sheet Mass Balance Inter-comparison Exercise (IMBIE). NASA and ESA established the first IMBIE with the aim of providing reconciled estimates of ice sheet mass balance. In 2012, IMBIE achieved this aim and reconciled measurements of ice sheet mass balance using satellite altimetry, gravimetry, and the input-output method. The IMBIE 2 effort aims to get a broader range of international scientists involved in the next mass balance assessment. One of the new key areas is the inclusion of precipitation patterns.

# EARTH SCIENCE RESEARCH

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA will continue collaboration with ESA on joint satellite calibration and validation activities for the Global Ecosystem Dynamics Investigation (GEDI) and NISAR missions and the ESA BIOMASS mission with a focus on terrestrial carbon storage and ecosystem dynamics. NASA is planning to participate jointly with ESA in the AfriSAR campaign in Gabon during FY 2017 to include flights of UAVSAR and Land, Vegetation, and Ice Sensor (LVIS).

The NASA interdisciplinary Sea Level Change Science team (established in 2014) will deliver integrative studies of sea level. This project will produce integrative assessments of sea level rise research focused on NASA's broad range of relevant missions and research. The principal objectives of the science team are to 1) improve our understanding of current and future sea level rise and its regional variation, 2) improve our understanding of changes in ice mass, both from the polar ice sheets and mountain glaciers, 3) produce new datasets useful to the sea level science research community and stakeholders, and 4) disseminate sea level research results from NASA's research programs.

In FY 2017 NASA will initiate research activities based on new competitions in ROSES 2016. These will be solicitations for interdisciplinary research with several crosscutting science foci. In addition, a new round of the Airborne Instrument Technology Transition (AITT) program competition will initiate research on technologies for integration and testing on board various NASA airplanes and UAVs. The intent of the research activities is to transition the instruments into suborbital tools that can participate in field experiments, evaluate new satellite instrument concepts, and/or provide calibration and validation of satellite instruments.

# Program Elements

## CARBON CYCLE SCIENCE TEAM

Carbon Cycle Science Team funds research on the distribution and cycling of carbon among Earth's active land, ocean, and atmospheric reservoirs.

## GLOBAL MODELING AND ASSIMILATION OFFICE

The Global Modeling and Assimilation Office create global climate and Earth system component models using data from Earth science satellites and aircraft. Investigators can then use these products worldwide to further their research.

## AIRBORNE SCIENCE

The Airborne Science project is responsible for providing manned and unmanned aircraft systems that further science and advance the use of satellite data. NASA uses these assets worldwide in campaigns to investigate extreme weather events, observe Earth system processes, obtain data for earth science modeling activities, and calibrate instruments flying aboard earth science spacecraft. NASA Airborne Science platforms support mission definition and development activities. For example, these activities include:

- Conducting instrument development flights;
- Gathering ice sheet observations as gap fillers between missions (e.g., Operation IceBridge);
- Serving as technology test beds for Instrument Incubator Program missions;
- Serving as the observation platforms for research campaigns, such as those competitively selected under the suborbital portion of Earth Venture; and
- Calibrating and validating space-based measurements and retrieval algorithms.

## OZONE TRENDS SCIENCE

The Ozone Trends Science project produces a consistent, calibrated ozone record used for trend analyses and other studies.

## INTERDISCIPLINARY SCIENCE

Interdisciplinary Science includes science investigations, as well as calibration and validation activities, that ensure the utility of space-based measurements. In addition, it supports focused fieldwork (e.g., airborne campaigns) and specific facility instruments upon which fieldwork depends.

## EARTH SCIENCE RESEARCH AND ANALYSIS

Earth Science Research and Analysis is the core of the research program and funds the analysis and interpretation of data from NASA's satellites. This project funds the scientific activity needed to establish a rigorous base for the satellites' data and their use in computational models.

## FELLOWSHIPS AND NEW INVESTIGATORS

The Fellowships and New Investigators project supports graduate and early career research in the areas of Earth system research and applied science.

## SPACE GEODESY

The Space Geodesy Project (SGP) provides global geodetic positioning and support for geodetic reference frames necessary for climate change and geohazards research. Geodesy is the science of measuring Earth's shape, gravity, and rotation and how these properties change over time. The SGP manages the operations and development of NASA's Space Geodetic Network that is comprised of the following major space geodetic observing systems: Very Long Baseline Interferometry, Satellite Laser Ranging, and Global Navigation Satellite System. It currently develops the next generation Space Geodetic Stations. The Space Geodesy project began in 2011. It is a GSFC and Jet Propulsion Laboratory (JPL) partnership, with participation from the Smithsonian Astrophysical Observatory and the University of Maryland.

# EARTH SCIENCE RESEARCH

## CARBON MONITORING SYSTEM

Carbon Monitoring System complements NASA's overall program in carbon cycle science and observations by producing and distributing products to the community regarding the flux of carbon between the surface and atmosphere, as well as the stores of carbon on the surface.

## EARTH SCIENCE DIRECTED RESEARCH AND TECHNOLOGY

Earth Science Directed Research and Technology funds the civil service staff who work on emerging Earth Science flight projects, instruments, and research.

## GLOBAL LEARNING AND OBSERVATIONS TO BENEFIT THE ENVIRONMENT

Global Learning and Observations to Benefit the Environment (GLOBE), previously funded under the former Earth Science Education and Outreach project, is a worldwide hands-on primary and secondary school-based science and education program that promotes collaboration among students, teachers, and scientists to conduct inquiry-based investigations about our environment. NASA works in close partnership with NOAA and NSF Earth System Science Projects to study the dynamics of Earth's environment, focused on atmosphere, hydrology, soil, and land cover. Students take measurements, analyze data, and participate in research in collaboration with scientists.

## SCIENTIFIC COMPUTING

The Scientific Computing project funds NASA's Earth Science Discover computing system, software engineering, and user interface projects at GSFC, including climate assessment modeling. Scientific Computing supports Earth system science modeling activities based on data collected by earth science spacecraft. The system is separate from the High End Computing Capability (HECC), so it can be close to the satellite data archives at GSFC. The proximity to the data and the focus on satellite data assimilation makes the Discover cluster unique in the ability to analyze large volumes of satellite data quickly. The system currently has approximately 79,000 computer processor cores.

## HIGH END COMPUTING CAPABILITY (HECC)

HECC focuses on the Endeavour, Merope, and Pleiades supercomputer systems and the associated network connectivity, data storage, data analysis, visualization, and application software support. It serves the supercomputing needs of all NASA mission directorates and NASA-supported principal investigators at universities. The Science funding supports the operation, maintenance, and upgrade of NASA's supercomputing capability, while the Strategic Capabilities Assets Program provides oversight. These three supercomputer systems, with approximately 211,000 computer processor cores, support NASA's aeronautics, human exploration, and science missions. For example, the systems are used to model the aerodynamic characteristics of the Space Launch System (SLS) at different attach angles and different air speeds. The systems also analyze the Kepler mission observation data to search for habitable exoplanets.

# EARTH SCIENCE RESEARCH

## DIRECTORATE SUPPORT

The Directorate Support project funds the Science Mission Directorate's (SMD) institutional and crosscutting activities including: National Academies studies, proposal peer review processes, printing and graphics, information technology, the NASA Postdoctoral Fellowship program, working group support, independent assessment studies, procurement support for the award and administration of all grants, and other administrative tasks.

## Program Schedule

| Date | Significant Event |
|---|---|
| Q2 FY 2016 | ROSES-2016 solicitation |
| Q1 FY 2017 | ROSES-2016 selection within six to nine months of receipt of proposals |
| Q2 FY 2017 | ROSES-2017 solicitation |
| Q1 FY 2018 | ROSES-2017 selection within six to nine months of receipt of proposals |

## Program Management & Commitments

| Program Element | Provider |
|---|---|
| Carbon Cycle Science Team | Provider: Various and defined in the acquisition strategy<br>Lead Center: Headquarters (HQ)<br>Performing Center(s): HQ, JPL, GSFC<br>Cost Share Partner(s): USGCRP and Subcommittee on Ocean Science and Technology (SOST) agencies |
| Global Modeling and Assimilation Office | Provider: Various<br>Lead Center: HQ<br>Performing Center(s): GSFC<br>Cost Share Partner(s): N/A |
| Airborne Science | Provider: Various<br>Lead Center: HQ<br>Performing Center(s): Armstrong Flight Research Center (AFRC), Ames Research Center (ARC), GSFC Wallops Flight Facility (WFF), Glenn Research Center (GRC), Johnson Space Center (JSC), Langley Research Center (LaRC)<br>Cost Share Partner(s): Federal Aviation Administration (FAA), Department of Defense (DoD), Department of Energy (DOE), NOAA, NSF |

# EARTH SCIENCE RESEARCH

| Program Element | Provider |
|---|---|
| Scientific Computing | Provider: GSFC<br>Lead Center: HQ<br>Performing Center(s): GSFC<br>Cost Share Partner(s): N/A |
| Ozone Trends Science | Provider: Various and defined in the acquisition strategy<br>Lead Center: HQ<br>Performing Center(s): LaRC, GSFC<br>Cost Share Partner(s): USGCRP and SOST agencies |
| Interdisciplinary Science | Provider: Various<br>Lead Center: HQ<br>Performing Center(s): HQ, JPL, GSFC, ARC, AFRC, GRC, LaRC, MSFC, JSC<br>Cost Share Partner(s): USGCRP and SOST agencies |
| Earth Science Research and Analysis | Provider: Various and defined in the acquisition strategy<br>Lead Center: HQ<br>Performing Center(s): All NASA Centers<br>Cost Share Partner(s): USGCRP and SOST agencies |
| High-End Computing Capability | Provider: ARC<br>Lead Center: HQ<br>Performing Center(s): ARC<br>Cost Share Partner(s): N/A |
| Directorate Support | Provider: HQ<br>Lead Center: HQ<br>Performing Center(s):<br>Cost Share Partner(s); None |
| Fellowships and New Investigators | Provider: Various<br>Lead Center: HQ<br>Performing Center(s): All NASA Centers<br>Cost Share Partner(s): N/A |
| Space Geodesy | Provider: Various<br>Lead Center: GSFC<br>Performing Centers: GSFC, JPL<br>Cost Share Partners: None |
| Carbon Monitoring System | Provider: Various and defined in the acquisition strategy<br>Lead Center: HQ<br>Performing Center(s): JPL, GSFC, ARC<br>Cost Share Partner(s): U.S. Forest Service, DOE, NOAA |

# EARTH SCIENCE RESEARCH

| Program Element | Provider |
|---|---|
| Global Learning and Observations to Benefit the Environment | Provider: University Corporation for Atmospheric Research<br>Lead Center: HQ<br>Performing Center(s): HQ, GSFC<br>Cost Share Partner(s): N/A |

## Acquisition Strategy

NASA implements the Earth Science Research program via competitively selected research awards. NASA releases research solicitations each year in the ROSES NASA Research Announcements. All proposals in response to NASA ROSES are peer reviewed and selected based on defined criteria. The program competitively awards at least 90 percent of its research program funds to investigators from academia, the private sector, and NASA Centers.

### INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Relevance | NASA Advisory Council Earth Science Subcommittee | 2015 | To review progress towards Earth Science objectives in the NASA Strategic Plan | All six science focus areas were rated green as documented in the FY 2015 Performance and Accountability Report | 2016; annually thereafter |

# EARTH SYSTEMATIC MISSIONS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Ice, Cloud, and land Elevation Satellite (ICESat-2) | 126.5 | 117.4 | **112.4** | 66.6 | 14.2 | 14.2 | 14.4 |
| GRACE-FO | 84.7 | 59.9 | **33.7** | 20.5 | 11.3 | 12.3 | 12.2 |
| Surface Water and Ocean Topography (SWOT) | 83.8 | -- | **83.7** | 105.9 | 126.3 | 81.0 | 42.0 |
| NASA-ISRO Synthetic Aperture Radar (NISAR) | 50.6 | -- | **68.5** | 85.0 | 150.0 | 145.0 | 100.0 |
| Other Missions and Data Analysis | 481.8 | -- | **634.7** | 687.5 | 719.5 | 752.6 | 831.6 |
| **Total Budget** | **827.3** | **--** | **933.0** | **965.5** | **1021.3** | **1005.0** | **1000.1** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*


**On November 5, 2015, two dams collapsed in southeastern Brazil, sending a torrent of mining sludge through the village of Bento Rodrigues. The Operational Land Imager (OLI) on Landsat 8 captured this natural-color view of the village and the surrounding region after the catastrophe. As part of the joint NASA-USGS Sustainable Land Imaging program, NASA has begun work on Landsat-9, which will extend the U.S. record of land images to half a century.**

Earth Systematic Missions (ESM) includes a broad range of multi-disciplinary science investigations aimed at understanding the Earth system and its response to natural and human-induced forces and changes. Understanding these forces will help determine how to predict future changes and mitigate or adapt to these changes.

The ESM program develops Earth-observing satellite missions, manages the operation of these missions once on orbit, and produces mission data products in support of the research, applications, and policy communities.

Interagency and international partnerships are a central element throughout the ESM program. Several on-orbit missions provide data products in near-real time for use by U.S. and international meteorological agencies and disaster responders. Five missions involve significant international or interagency collaboration in development. The Landsat Data Continuity Mission (LDCM), now operating on orbit as Landsat 8, involves collaboration with the U.S Geological Survey (USGS). The GPM mission, now operating on orbit, is a partnership with the Japanese Aerospace Exploration Agency (JAXA), and the GRACE Follow-On (GRACE-FO) mission is a partnership between NASA and the German Research Centre for Geosciences (GFZ). The SWOT mission includes significant collaborations with the Centre National d'Etudes' Spatiales (CNES), the Canadian

# EARTH SYSTEMATIC MISSIONS

Space Agency (CSA), and the United Kingdom Space Agency (UKSA). The NISAR mission is a major collaboration between NASA and the Indian Space Research Organisation (ISRO).

## EXPLANATION OF MAJOR CHANGES IN FY 2017

Landsat 9 entered the formulation phase, with an anticipated launch of 2021. This budget does not include the Thermal Infrared Free Flyer project. NASA has increased the Radiation Budget Instrument (RBI) project estimated cost due to technical and programmatic challenges. The Altimetry Follow-On (AFO) mission, renamed Sentinel-6, will support NASA's contributions to both ESA Sentinel-6A and -6B. NASA created a new Ocean Salinity Science Team project to consolidate research investments in ocean salinity science, due to the termination of the Aquarius mission. SMAP transitioned to operations after a successful launch. NASA decommissioned QuikSCAT and TRMM and the missions are completing their final data processing.

# ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| | | Actual | Enacted | Request | Notional | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Budget Authority (in $ millions)** | **Prior** | **FY 2015** | **FY 2016** | **FY 2017** | **FY 2018** | **FY 2019** | **FY 2020** | **FY 2021** | **BTC** | **Total** |
| Formulation | 249.1 | 0.0 | 0.0 | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 249.1 |
| Development/Implementation | 353.8 | 126.5 | 117.4 | **110.8** | 55.2 | 0.0 | 0.0 | 0.0 | 0.0 | 763.7 |
| Operations/Close-out | 0.0 | 0.0 | 0.0 | **1.6** | 11.4 | 14.2 | 14.2 | 9.4 | 0.0 | 50.8 |
| **2016 MPAR LCC Estimate** | **602.9** | **126.5** | **117.4** | **112.4** | **66.6** | **14.2** | **14.2** | **9.4** | **0.0** | **1063.6** |
| **Total Budget** | **603.0** | **126.5** | **117.4** | **112.4** | **66.6** | **14.2** | **14.2** | **14.4** | **1.9** | **1070.5** |
| Change from FY 2016 | | | | **-5.0** | | | | | | |
| Percentage change from FY 2016 | | | | **-4.3%** | | | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**ICESat-2 will use a multi-beam micropulse laser altimeter to measure the topography of the Greenland and Antarctic ice sheets as well as the thickness of Arctic and Antarctic sea ice. The satellite LIDAR also will measure vegetation canopy heights and support other NASA environmental monitoring missions. By discovering the anatomy of ice loss, researchers may be able to forecast how the ice sheets will melt in the future and what impact this will have on sea-levels.**

### PROJECT PURPOSE

The ICESat-2 mission will serve as an ICESat follow-on satellite to continue the assessment of polar ice changes. ICESat-2 will also measure vegetation canopy heights, allowing estimates of biomass and carbon in above ground vegetation in conjunction with related missions, and allow measurements of solid earth properties.

ICESat-2 will continue to provide an important record of multi-year elevation data needed to determine ice sheet mass balance and cloud property information. It will also provide topography and vegetation data around the globe in addition to the polar-specific coverage over the Greenland and Antarctic ice sheets.

The ICESat-2 mission is a Tier 1 mission, recommended by the National Academies. It entered formulation in FY 2010 and entered implementation in FY 2013.

For more information, go to http://icesat.gsfc.nasa.gov/icesat2.

# ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

| Formulation | Development | Operations |
|---|---|---|

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## PROJECT PARAMETERS

The ICESat-2 observatory employs a dedicated spacecraft with a multi-beam photon-counting surface elevation lidar, which measures distance by illuminating the Earth's surface with a laser and analyzing the reflected light. ICESat-2 will continue the measurements begun with the first ICESat mission, which launched in 2003, and will improve upon ICESat by incorporating a micro-pulse multi-beam laser to provide dense cross-track sampling, improving elevation estimates over inclined surfaces and very rough (e.g., crevassed) areas and improving lead detection for above-water sea ice estimates.

## ACHIEVEMENTS IN FY 2015

The project completed the spacecraft and began testing activities. Almost all Advanced Topographic Laser Altimeter System (ATLAS) instrument subsystems were completed, delivered, and integrated and overall instrument testing also began.

## WORK IN PROGRESS IN FY 2016

The final ATLAS subsystems will be completed, delivered, and integrated during early FY 2016. The project will complete final ATLAS instrument testing with corresponding instrument delivery during late FY 2016 and hold the Mission Operations Review.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

The project team will integrate the instrument with the spacecraft and test the resultant observatory. Associated reviews scheduled in FY 2017 include the System Integration Review (SIR) and the Key Decision Point (KDP)-D.

## SCHEDULE COMMITMENTS/KEY MILESTONES

NASA plans to launch ICESat-2 in June 2018 to begin a three-year prime mission. The following timeline shows the development agreement schedule per the rebaseline plan from May 2014.

| Milestone | Confirmation Baseline Date | FY 2017 PB Request |
|---|---|---|
| KDP-C | Dec 2012 | Dec 2012 |
| Critical Design Review (CDR) | Feb 2014 | Feb 2014 |
| New Baseline | Feb 2015 | Feb 2015 |

# ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

| Formulation | **Development** | Operations |
|---|---|---|

| Milestone | Confirmation Baseline Date | FY 2017 PB Request |
|---|---|---|
| Launch | Jun 2018 | Jun 2018 |
| End of Prime Mission | Sep 2021 | Sep 2021 |

## Development Cost and Schedule

| Base Year | Base Year Develop-ment Cost Estimate ($M) | JCL (%) | Current Year | Current Year Develop-ment Cost Estimate ($M) | Cost Change (%) | Key Milestone | Base Year Milestone Data | Current Year Milestone Data | Milestone Change (mths) |
|---|---|---|---|---|---|---|---|---|---|
| 2015 | 763.7 | >70 | 2016 | 763.7 | 0 | Launch | Jun 2018 | Jun 2018 | 0 |

*Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.*

## Development Cost Details

| Element | Base Year Development Cost Estimate ($M) | Current Year Development Cost Estimate ($M) | Change from Base Year Estimate ($M) |
|---|---|---|---|
| **TOTAL:** | **763.8** | **763.7** | **-0.1** |
| Aircraft/Spacecraft | 106.0 | 107.6 | 1.6 |
| Payloads | 239.1 | 289.1 | 50.0 |
| Systems Integration and Test (I&T) | 21.6 | 12.5 | -9.1 |
| Launch Vehicle | 118.8 | 118.8 | 0.0 |
| Ground Systems | 55.4 | 57.5 | 2.1 |
| Science/Technology | 31.0 | 32.7 | 1.7 |
| Other Direct Project Costs | 191.9 | 145.5 | -46.4 |

# ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

| Formulation | Development | Operations |
|---|---|---|

## Project Management & Commitments

GSFC has project management responsibility for ICESat-2.

| Element | Description | Provider Details | Change from Baseline |
|---|---|---|---|
| ATLAS Instrument | Advanced Topographic Laser Altimeter System | Provider: GSFC<br>Lead Center: GSFC<br>Performing Center(s): GSFC<br>Cost Share Partner(s): N/A | N/A |
| Launch Vehicle | Provides launch service and entry into proper Earth orbit | Provider: United Launch Alliance (ULA)<br>Lead Center: GSFC<br>Performing Center(s): KSC<br>Cost Share Partner(s): N/A | N/A |
| Ground System | Provides control of observatory operations, science data processing and distribution | Provider: Orbital ATK<br>Lead Center: GSFC<br>Performing Center(s): GSFC<br>Cost Share Partner(s): N/A | N/A |
| Spacecraft | Platform provides thermal and attitude control, power, and communications with the instrument | Provider: Orbital ATK<br>Lead Center: GSFC<br>Performing Center(s): GSFC<br>Cost Share Partner(s): N/A | N/A |

## Project Risks

| Risk Statement | Mitigation |
|---|---|
| If: The instrument hardware experiences development problems during testing,<br>Then: The delay of instrument completion increases the overall mission cost. | During the re-baseline exercise, NASA added 18 months of funded schedule reserves to the schedule to accommodate problem resolution during fabrication, integration, and testing. |

## Acquisition Strategy

GSFC is responsible for the design and testing of the ATLAS instrument. NASA competitively selected the spacecraft vendor, Orbital ATK, which will provide the ground system element through a contract option. NASA competitively selected ULA as the launch services vendor.

# ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

| Formulation | Development | Operations |
|---|---|---|

## MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Ground System | Orbital ATK | Dulles, VA |
| Spacecraft | Orbital ATK | Gilbert, AZ |
| Launch Service | ULA | Decatur, AL |

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | Standing Review Board (SRB) | Dec 2012 | KDP-C | Mission was approved to enter development | Feb 2014 |
| Perform-ance | SRB | Feb 2014 | Mission CDR | Mission CDR was successfully completed | Oct 2016 |
| Perform-ance | SRB | Oct 2016 | KDP-D | TBD | Jul 2017 |
| Perform-ance | SRB | Jul 2017 | Operational Readiness Review (ORR) | TBD | N/A |

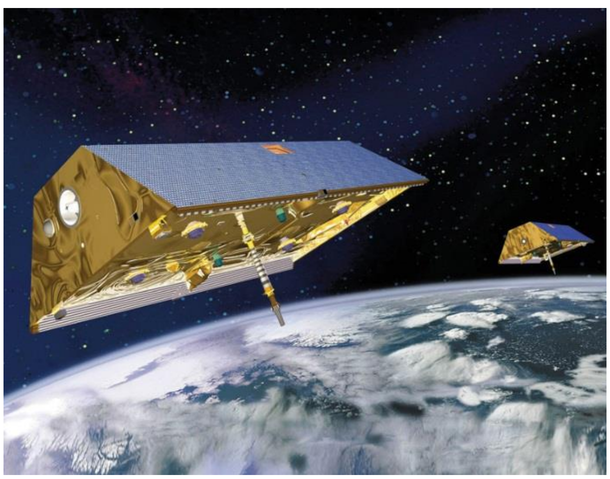
# GRACE-FO

## FY 2017 Budget

| Budget Authority (in $ millions) | Prior | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 | BTC | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Formulation | 107.4 | 0.0 | 0.0 | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 107.4 |
| Development/Implementation | 75.6 | 84.7 | 59.9 | **33.7** | 9.5 | 0.0 | 0.0 | 0.0 | 0.0 | 263.4 |
| Operations/Close-out | 0.0 | 0.0 | 0.0 | **0.0** | 11.0 | 11.3 | 12.3 | 12.2 | 14.4 | 61.2 |
| **2016 MPAR LCC Estimate** | **183.0** | **84.7** | **59.9** | **33.7** | **20.5** | **11.3** | **12.3** | **12.2** | **14.4** | **432.0** |
| **Total Budget** | **183.0** | **84.7** | **59.9** | **33.7** | **20.5** | **11.3** | **12.3** | **12.2** | **14.4** | **431.9** |
| Change from FY 2016 | | | | **-26.2** | | | | | | |
| Percentage change from FY 2016 | | | | **-43.7%** | | | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**GRACE-FO is a successor to the original GRACE mission, which began orbiting Earth in 2002. The two GRACE-FO satellites will use the same kind of microwave ranging system as GRACE, and so can expect to achieve a similar level of precision. But they will also test an experimental instrument using lasers instead of microwaves, which promises to make the measurement of their separation distance at least 20 times more precise.**

### PROJECT PURPOSE

The GRACE-FO mission will allow scientists to gain new insights into the dynamic processes in Earth's interior, currents in the oceans, and variations in the extent of ice coverage. Data from the mission, combined with other existing sources of data, will greatly improve scientific understanding of glaciers and hydrology.

GRACE-FO will obtain the same extremely high-resolution global models of Earth's gravity field, including how it varies over time, as in the original GRACE mission (launched in 2002). GRACE-FO data is vital to ensuring there is a minimal gap in gravitational field measurements following the decommissioning of the currently operating GRACE mission. GRACE-FO includes a partnership with the German Research Centre for Geosciences.

# GRACE-FO

## EXPLANATION OF MAJOR CHANGES IN FY 2017

NASA has agreed to change the launch site for the GRACE-FO mission from Baikonur, Kazakhstan to Yasny, Russia at the request of the International Space Company Kosmotras, the launch service provider under contract to GFZ.

## PROJECT PARAMETERS

The GRACE-FO observatory employs two dedicated spacecraft, launched into a near-circular polar orbit. As the two spacecraft orbit Earth, slight variations in gravity will alter the spacecraft speed and distance relative to each other. Scientists use the speed and distance changes to extrapolate and map Earth's gravitational field.

The GRACE-FO instrument suite includes the Microwave Instrument, which accurately measures changes in the speed and distance between the two spacecraft. The accelerometer instrument measures all non-gravitational accelerations (e.g., atmospheric drag, solar radiation pressure, attitude control, and thruster operation) on each GRACE-FO satellite. The Laser Ranging Interferometer is a technology demonstration and is a partnership between the United States and Germany. NASA will use the science data from the GRACE-FO mission to generate an updated model of Earth's gravitational field approximately every 30 days for the 5-year lifetime of the prime mission.

## ACHIEVEMENTS IN FY 2015

The GRACE-FO project successfully completed its critical design review in February 2015 and its system integration review in July 2015. The project proceeded to its I&T phase in August 2015.

## WORK IN PROGRESS IN FY 2016

The deliveries of the accelerometers, the microwave instruments, and the laser ranging interferometers for observatory integration will occur in FY 2016. The project plans to complete observatory integration in FY 2016.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

Observatory environmental testing, shipment to the launch site, and launch processing are planned for FY 2017, in order to launch by May 2018.

## SCHEDULE COMMITMENTS/KEY MILESTONES

| Milestone | Confirmation Baseline Date | FY 2017 PB Request |
|---|---|---|
| KDP-C | Feb 2014 | Feb 2014 |
| CDR | Feb 2015 | Feb 2015 |
| KDP-D | Aug 2015 | Aug 2015 |

# GRACE-FO

| Milestone | Confirmation Baseline Date | FY 2017 PB Request |
|---|---|---|
| Launch (or equivalent) | Feb 2018 | Feb 2018 |
| Start Phase E | May 2018 | May 2018 |
| End of Prime Mission | Feb 2023 | Feb 2023 |

## Development Cost and Schedule

| Base Year | Base Year Develop-ment Cost Estimate ($M) | JCL (%) | Current Year | Current Year Develop-ment Cost Estimate ($M) | Cost Change (%) | Key Milestone | Base Year Milestone Data | Current Year Milestone Data | Milestone Change (mths) |
|---|---|---|---|---|---|---|---|---|---|
| 2015 | 264 | 70 | 2016 | 263.4 | 0 | Launch | Feb 2018 | Feb 2018 | 0 |

*Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.*

## Development Cost Details

NASA approved GRACE-FO to proceed into integration and test in August 2015.

| Element | Base Year Development Cost Estimate ($M) | Current Year Development Cost Estimate ($M) | Change from Base Year Estimate ($M) |
|---|---|---|---|
| **TOTAL:** | **264.0** | **263.4** | **-0.6** |
| Aircraft/Spacecraft | 118.7 | 124.1 | 5.4 |
| Payloads | 32.1 | 37.3 | 5.2 |
| Systems I&T | 0 | 0 | 0 |
| Launch Vehicle | 0 | 0 | 0 |
| Ground Systems | 0 | 0 | 0 |
| Science/Technology | 12.3 | 15.0 | 2.7 |
| Other Direct Project Costs | 100.9 | 87.0 | -13.9 |

# GRACE-FO

## Project Management & Commitments

The Earth Systematic Missions Program at GSFC manages GRACE-FO. NASA has assigned responsibility for implementation to JPL.

| Element | Description | Provider Details | Change from Baseline |
|---|---|---|---|
| Spacecraft | Provides platform for the instruments | Provider: Airbus Defence & Space (Germany)<br>Lead Center: N/A<br>Performing Center(s): JPL<br>Cost Share Partner(s): N/A | N/A |
| Microwave Instrument | Measures the distance between the spacecraft as a function of time | Provider: JPL<br>Lead Center: JPL<br>Performing Center(s): JPL<br>Cost Share Partner(s): N/A | N/A |
| Accelerometers | Measures all non-gravitational accelerations of the satellite(s) | Provider: French Office National d'Etudes et Recherches Aérospatiales (ONERA)<br>Lead Center: JPL<br>Performing Center(s): JPL<br>Cost Share Partner(s): N/A | N/A |
| Laser Ranging Interferometer | Heterodyne interferometric laser will measure the distance between the two spacecraft as a function of time | Provider: JPL and GFZ<br>Lead Center: JPL<br>Performing Center(s): JPL<br>Cost Share Partner(s): GFZ | N/A |
| Launch Vehicle | Delivers observatory into Earth orbit | Provider: JSC Kosmotras (Russia)<br>Lead Center: N/A<br>Performing Center(s): N/A<br>Cost Share Partner(s): GFZ | N/A |

# GRACE-FO

## Project Risks

| Risk Statement | Mitigation |
|---|---|
| If: The contributions from the international partner for the GRACE-FO mission are delayed or cannot be provided as planned,<br>Then: There could be a delay to the GRACE-FO mission as well. | NASA and JPL will work diligently with its international partners to assess the status of their deliverables on a routine basis and assist them with mitigating any technical or programmatic issues if they arise, as International Traffic in Arms Regulations (ITAR) and other international regulations allow. NASA will determine the best course of action for the project, based on the given circumstances at that time. |

## Acquisition Strategy

The acquisition strategy for GRACE-FO leveraged GRACE heritage by using sole source procurement to the same vendors for major components. NASA has completed all major acquisitions.

### MAJOR CONTRACTS/AWARDS

None.

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Spacecraft | Airbus Defence & Space | Germany |
| Microwave Instrument Ultra Stable Oscillator | Applied Physics Laboratory-Johns Hopkins University | Laurel, MD |
| Microwave Assemblies | Space Systems/Loral | Palo Alto, CA |
| Accelerometers | ONERA | France |

# GRACE-FO

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | SRB | Feb 2014 | KDP-C Milestone Review | Project approved to proceed into development | Aug 2015 |
| Perform-ance | SRB | Aug 2015 | KDP-D Milestone Review | Project approved to enter the integration and test phase | Jul 2017 |
| Perform-ance | SRB | Jul 2017 | Flight Readiness Review (FRR) | TBD | N/A |

# SURFACE WATER AND OCEAN TOPOGRAPHY (SWOT)

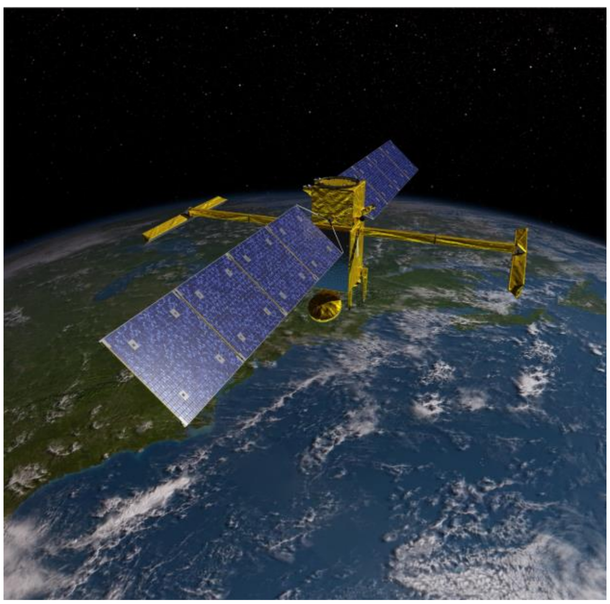
| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **83.8** | **--** | **83.7** | **105.9** | **126.3** | **81.0** | **42.0** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**An artist's conception shows the Surface Water Ocean Topography (SWOT) satellite, which entered the formulation phase in November 2012. SWOT will make high-resolution, wide-swath altimetric measurements of the world's oceans and fresh water bodies to understand their circulation, surface topography, and storage. This multi-disciplinary, cooperative international mission will produce science and data products that will allow for fundamental advances in the understanding of the global water cycle.**

### PROJECT PURPOSE

The SWOT mission will improve our understanding of the world's oceans and terrestrial surface waters. The mission, through broad swath altimetry, will make high-resolution measurements of ocean circulation, its kinetic energy, and its dissipation. These measurements will improve ocean circulation models, leading to better prediction of weather and climate. The mission will also revolutionize knowledge of the surface water inventory on the continents by precise measurement of water levels in millions of lakes and water bodies and the discharge of all major rivers. This will allow for deeper understanding of the natural water cycle and the informed control of this resource.

The 2007 National Academies decadal survey of Earth Science and the NASA's 2010 Climate Plan endorsed SWOT. The mission will complement the Jason oceanography missions, as well as other NASA missions currently in operation and development to measure the global water cycle (GPM, SMAP, and GRACE-FO). NASA will collaborate with CNES, CSA, and UKSA to accomplish this mission.

### EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

# SURFACE WATER AND OCEAN TOPOGRAPHY (SWOT)

| Formulation | Development | Operations |
|---|---|---|

## PROJECT PRELIMINARY PARAMETERS

SWOT will provide broad-swath sea surface heights and terrestrial water heights for at least 90 percent of the globe using a dual-antenna Ka-band Radar Interferometer (KaRIn). The SWOT payload will also include a precision orbit determination system consisting of Global Positioning System-Payload (GPSP), Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) receivers, and a Laser Retro-reflector Assembly (LRA). In addition, SWOT carries a Nadir Altimeter, and a radiometer for tropospheric path delay corrections. The mission will operate for three years.

## ACHIEVEMENTS IN FY 2015

The SWOT project successfully completed the KaRIn Antenna and Mechanical/Thermal Payload Structure Preliminary Design Review (PDR), the flight system interface and KaRIn radio frequency unit peer reviews, and all technology development for the KaRIn instrument.

## WORK IN PROGRESS IN FY 2016

The SWOT project will complete the mission PDR, and will undergo a confirmation review in FY 2016. NASA will also select the launch vehicle.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

The project will complete the KaRIn CDR and the mission CDR.

## ESTIMATED PROJECT SCHEDULE

| Milestone | Formulation Authorization Document | FY 2017 PB Request |
|---|---|---|
| Formulation Authorization | Nov 2012 | Nov 2012 |
| KDP-B | Jun 2014 | Jun 2014 |
| PDR | Jan 2016 | Apr 2016 |
| KDP-C | Mar 2016 | May 2016 |
| CDR | Jun 2017 | Jun 2017 |
| KDP-D | Aug 2019 | Aug 2019 |
| Launch | Oct 2020 | Oct 2020 |

# SURFACE WATER AND OCEAN TOPOGRAPHY (SWOT)

| Formulation | Development | Operations |
|---|---|---|

## Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review.

| KDP-B Date | Estimated Life Cycle Cost Range ($M) | Key Milestone | Key Milestone Estimated Date Range |
|---|---|---|---|
| Jun 2014 | 647–757 | Launch | Oct 2020 |

## Project Management & Commitments

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| KaRIn | Makes swath measurements of sea surface topography and lake and river heights | Provider: NASA, CNES, CSA, UKSA<br>Lead Center: JPL<br>Performing Center(s): JPL<br>Cost Share Partner(s): CNES (RFU), CSA (EIK), UKSA (Duplexer) | N/A |
| Advanced Microwave Radiometer (AMR) | Provides wet tropospheric delay correction of KaRIn | Provider: NASA<br>Lead Center: JPL<br>Performing Center(s): JPL<br>Cost Share Partner(s): N/A | N/A |
| GPSP | Provides orbit determination | Provider: NASA<br>Lead Center: JPL<br>Performing Center(s): JPL<br>Cost Share Partner(s): N/A | N/A |
| LRA | Provides orbit determination | Provider: NASA<br>Lead Center: JPL<br>Performing Center(s): JPL<br>Cost Share Partner(s): N/A | N/A |
| X-band Telecom | Provides downlink of science data | Provider: NASA<br>Lead Center: JPL<br>Performing Center(s): JPL<br>Cost Share Partner(s): N/A | N/A |

# SURFACE WATER AND OCEAN TOPOGRAPHY (SWOT)

| Formulation | Development | Operations |
|---|---|---|

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| Nadir Altimeter | Measures Jason-heritage ocean surface topography at nadir | Provider: CNES<br>Lead Center: N/A<br>Performing Center(s): N/A<br>Cost Share Partner(s): CNES | N/A |
| DORIS | Provides orbit determination | Provider: CNES<br>Lead Center: N/A<br>Performing Center(s): N/A<br>Cost Share Partner(s): CNES | N/A |
| Spacecraft Bus | Provides instrument platform | Provider: CNES<br>Lead Center: N/A<br>Performing Center(s): N/A<br>Cost Share Partner(s): CNES | N/A |
| Launch Vehicle | Delivers spacecraft to orbit | Provider: NASA<br>Lead Center: JPL<br>Performing Center(s): KSC<br>Cost Share Partner(s): N/A | N/A |

## Project Risks

| Risk Statement | Mitigation |
|---|---|
| If: KaRIn critical path contributions from the multiple partners are not timely,<br>Then: It will delay delivery of the KaRIn instrument. | Project worked with CNES to define interfaces, requirements, test plans, and hardware exchanges early. NASA, CSA, and CNES synchronized the development schedules for KaRIn and Radio Frequency Unit (RFU). KaRIn radio frequency unit peer review and KaRIn PDR were successfully completed. |

## Acquisition Strategy

The acquisition strategy for SWOT leveraged Jason heritage by using JPL legacy instrument designs (AMR , GPSP, and LRA) and in-house build with a combination of sole source and competitive procurements. The KaRIn leverages Earth Science Technology Office investments and is an in-house development. The X-band Telecom will be a competitive procurement.

# SURFACE WATER AND OCEAN TOPOGRAPHY (SWOT)

| Formulation | Development | Operations |
| --- | --- | --- |

## MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
| --- | --- | --- |
| X-band Telecom | L3 for modulator, Tesat for traveling wave tube amplifiers | San Diego, CA, Backnang, Germany |

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
| --- | --- | --- | --- | --- | --- |
| Perform-ance | SRB | May 2014 | SRR/Mission Definition Review (MDR) | Project met all review success criteria | Apr 2016 |
| Perform-ance | SRB | Apr 2016 | PDR | TBD | Jun 2017 |
| Perform-ance | SRB | Jun 2017 | CDR | TBD | Jan 2019 |
| Perform-ance | SRB | Jan 2019 | SIR | TBD | Aug 2020 |
| Perform-ance | SRB | Aug 2020 | ORR | TBD | N/A |

# NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

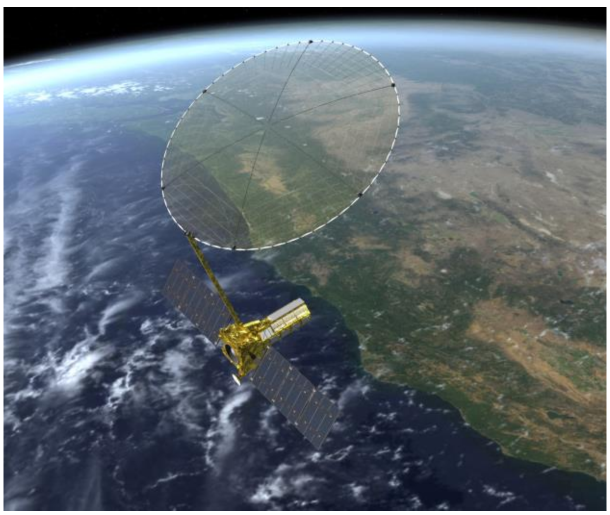
| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **50.6** | **--** | **68.5** | **85.0** | **150.0** | **145.0** | **100.0** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**The NISAR satellite, a joint mission between NASA and the Indian Space Research Organisation (ISRO), will be the first radar imaging satellite to use dual frequencies. NISAR will observe and take measurements of some of the planet's most complex processes, including ecosystem disturbances, ice-sheet collapse, and natural hazards.**

## PROJECT PURPOSE

The NISAR mission will provide an unprecedented, detailed view of the Earth using advanced radar imaging. The NISAR satellite will observe and take measurements of some of the planet's most complex processes, including ecosystem disturbances; ice sheet collapse; and natural hazards, such as earthquakes, tsunamis, volcanoes, and landslides. NISAR is a dual frequency (L- and S-band) Synthetic Aperture Radar (SAR) mission and data collected by the NISAR satellite will reveal information about the evolution and state of Earth's crust, help scientists understand more about our planet is changing processes and its effect in changing climate, and aid future resource and hazard management. The mission is currently in formulation in partnership with ISRO.

Scientists have proposed L-band SAR missions in various forms for over a decade. Scientists derived the L-band SAR science of the NISAR mission from Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI) (a 2007 Decadal Survey Tier 1 mission recommended by the National Academies).

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

# NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

| Formulation | Development | Operations |
| --- | --- | --- |

## PROJECT PRELIMINARY PARAMETERS

NASA will provide the L-band SAR. ISRO will provide the S-band SAR, the spacecraft bus, the launch vehicle, observatory integration and testing, and spacecraft operations. NASA/JPL will be providing the L-band SAR instrument and associated payload elements, including L-band electronics, radar feed, reflector and boom assembly, solid state recorder, GPS receiver, high-rate telecom system, and payload data subsystem.

## ACHIEVEMENTS IN FY 2015

The NISAR mission completed its System Requirement Review (SRR) and MDR in December 2014. NASA approved the project to enter formulation Phase B in February 2015.

## WORK IN PROGRESS IN FY 2016

In FY 2016, NASA will complete the preliminary design for NISAR. The NISAR project is in the process of defining and documenting the interface requirements between the major payload subsystems and the spacecraft. NASA will hold the PDR in June 2016, followed by the KDP-C review in September 2016.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA will complete the design of the NISAR mission, finalize all interface requirements, and will prepare for the CDR in early FY 2018.

## ESTIMATED PROJECT SCHEDULE

| Milestone | Formulation Authorization Document | FY 2017 PB Request |
| --- | --- | --- |
| Formulation Authorization | May 2014 | May 2014 |
| KDP-B | Feb 2015 | Feb 2015 |
| PDR | Aug 2016 | Aug 2016 |
| KDP-C | Sep 2016 | Sep 2016 |
| CDR | N/A | Jan 2018 |
| KDP-D | N/A | Mar 2019 |
| Launch | Dec 2020 | Dec 2020–Jun 2022 |

# NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

| Formulation | Development | Operations |
|---|---|---|

## Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or PDR.

| KDP-B Date | Estimated Life Cycle Cost Range ($M) | Key Milestone | Key Milestone Estimated Date Range |
|---|---|---|---|
| Feb 2015 | 718–808 | Launch | Dec 2020–Jun 2022 |

## Project Management & Commitments

JPL has project management responsibility for NISAR.

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| L-band SAR | Radar imaging payload | Provider: NASA<br>Lead Center: JPL<br>Performing Center(s): JPL<br>Cost Share Partner(s): N/A | N/A |
| S-band SAR | Radar imaging payload | Provider: ISRO<br>Lead Center: N/A<br>Performing Center(s): N/A<br>Cost Share Partner(s): ISRO | N/A |
| Spacecraft | Provides platform for the payload | Provider: ISRO<br>Lead Center: N/A<br>Performing Center(s): N/A<br>Cost Share Partner(s): ISRO | N/A |
| Launch Vehicle | Delivers observatory to orbit | Provider: ISRO<br>Lead Center: N/A<br>Performing Center(s): N/A<br>Cost Share Partner(s): ISRO | N/A |

# NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

| Formulation | Development | Operations |
|---|---|---|

## Project Risks

| Risk Statement | Mitigation |
|---|---|
| If: The ISRO-provided Geosynchronous Satellite Launch Vehicle GSLV Mark II launch vehicle reliability does not meet the NASA-ISRO joint requirements,<br>Then: There may be a significant delay in the launch date. | NASA and ISRO jointly defined five success criteria for the NISAR launch to proceed and both NASA and ISRO have documented and agreed to these criteria. On August 27, 2015, ISRO completed a successful GSLV launch and met one of the five criteria. |

## Acquisition Strategy

The design and build of the L-band SAR radar will be an in-house build at JPL, with subcontracts competed as appropriate.

### MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Reflector Antenna | Astro Aerospace | California |

### INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | SRB | Dec 2014 | SRR/MDR | Project met all review success criteria | Aug 2016 |
| Perform-ance | SRB | Aug 2016 | PDR | TBD | Jan 2018 |
| Perform-ance | SRB | Jan 2018 | CDR | TBD | Feb 2019 |
| Perform-ance | SRB | Feb 2019 | SIR | TBD | Oct 2020 |
| Perform-ance | SRB | Oct 2020 | ORR | TBD | N/A |

# OTHER MISSIONS AND DATA ANALYSIS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Earth Systematic Missions (ESM) Research | 12.8 | -- | **18.6** | 18.6 | 23.8 | 26.2 | 26.5 |
| Ocean Surface Topography Science Team | 6.1 | -- | **5.7** | 5.7 | 5.7 | 5.9 | 5.9 |
| Earth Observations Systems (EOS) Research | 23.1 | -- | **22.7** | 20.7 | 17.7 | 18.8 | 19.0 |
| Stratospheric Aerosol and Gas Experiment III (Sage III) | 24.3 | -- | **4.6** | 4.8 | 4.6 | 4.6 | 4.6 |
| Sustainable Land Imaging | 3.8 | -- | **5.8** | 11.0 | 11.1 | 36.0 | 64.9 |
| Radiation Budget Instrument (RBI) | 44.7 | -- | **54.3** | 46.0 | 17.2 | 9.4 | 6.8 |
| Earth from ISS | 3.8 | -- | **3.5** | 2.8 | 2.6 | 2.6 | 2.6 |
| Total Solar Irradiance Sensor-2 (TSIS-2) | 0.0 | -- | **9.6** | 23.9 | 36.9 | 26.5 | 17.0 |
| Earth Radiation Budget Science | 11.8 | -- | **14.0** | 13.7 | 13.6 | 13.8 | 14.0 |
| Ozone Mapping and Profiler Suite Limb Sounder (OMPS-L) | 4.3 | -- | **2.2** | 0.3 | 0.0 | 0.0 | 0.0 |
| Total Solar Irradiance Sensor-1 (TSIS-1) | 1.0 | -- | **19.6** | 4.2 | 3.4 | 3.4 | 3.5 |
| Sentinel-6 | 0.0 | -- | **42.5** | 56.4 | 71.3 | 66.5 | 37.2 |
| Pre-Aerosol, Clouds, and Ocean Ecosystem | 20.0 | -- | **88.8** | 78.8 | 144.4 | 196.0 | 137.1 |
| CLARREO Pathfinder | 0.0 | -- | **19.3** | 27.9 | 15.4 | 2.1 | 0.2 |
| Landsat 9 | 60.3 | -- | **130.8** | 179.3 | 166.4 | 128.3 | 109.0 |
| Decadal Survey Missions | 25.8 | -- | **15.4** | 14.4 | 15.5 | 38.8 | 204.2 |
| Earth Science Program Management | 29.5 | -- | **34.0** | 34.6 | 32.6 | 34.3 | 35.5 |
| Precipitation Science Team | 7.3 | -- | **6.9** | 6.9 | 6.9 | 7.1 | 7.2 |
| Ocean Winds Science Team | 4.5 | -- | **4.2** | 4.2 | 4.2 | 4.3 | 4.4 |
| Land Cover Science Project Office | 1.5 | -- | **1.5** | 1.5 | 1.5 | 1.6 | 1.6 |
| Ocean Salinity Science Team | 0.0 | -- | **3.9** | 7.8 | 7.8 | 8.0 | 8.1 |
| Soil Moisture Active and Passive (SMAP) | 63.1 | -- | **8.4** | 11.3 | 11.3 | 11.5 | 11.7 |
| Quick Scatterometer | 2.1 | -- | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| Tropical Rainfall Measuring Mission | 10.1 | -- | **3.2** | 0.0 | 0.0 | 0.0 | 0.0 |
| Deep Space Climate Observatory | 2.9 | -- | **1.7** | 1.2 | 1.2 | 0.8 | 0.0 |
| Global Precipitation Measurement (GPM) | 21.2 | -- | **21.1** | 20.0 | 20.0 | 20.1 | 20.0 |
| Landsat 8 | 2.2 | -- | **2.4** | 2.4 | 0.0 | 0.0 | 0.0 |
| Ocean Surface Topography Science Team (OSTST) | 2.2 | -- | **1.5** | 2.3 | 2.3 | 2.3 | 2.4 |
| Suomi National Polar-Orbiting Partnership (NPP) | 4.0 | -- | **3.4** | 3.4 | 3.5 | 3.6 | 3.7 |
| Terra | 26.2 | -- | **26.1** | 25.3 | 25.3 | 25.9 | 26.3 |
| Aqua | 27.8 | -- | **28.1** | 27.3 | 27.3 | 27.8 | 28.3 |
| Aura | 26.8 | -- | **23.9** | 25.9 | 25.9 | 26.4 | 29.8 |
| Solar Radiation and Climate Experiment (SORCE) | 5.4 | -- | **5.4** | 4.7 | 0.0 | 0.0 | 0.0 |
| Earth Observing-1 | 2.6 | -- | **1.4** | 0.0 | 0.0 | 0.0 | 0.0 |
| Active Cavity Radiometer Irradiance Monitor Satellite (ACRIMSat) | 0.6 | -- | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 |

# OTHER MISSIONS AND DATA ANALYSIS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **481.8** | **--** | **634.7** | **687.5** | **719.5** | **752.6** | **831.6** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

Earth Systematic Missions Other Missions and Data Analysis includes operating missions and their science teams and competed research projects. Mission science teams define the scientific requirements for their missions and generate algorithms used to process the data into useful data products. The research projects execute competitively selected investigations related to specific mission measurements.

Also included here are missions in pre-formulation, such as PACE and Sentinel-6; missions in formulation, such as Landsat 9 and Radiation Budget Instrument (RBI); and smaller missions in formulation and development, such as TSIS (Total Solar Irradiance Sensor)-1 and TSIS-2.

## Mission Planning and Other Projects

### EARTH SYSTEMATIC MISSIONS (ESM) RESEARCH

Earth Systematic Missions (ESM) Research funds various science teams for the Earth Systematic missions. These science teams are composed of competitively selected individual investigators who analyze data from the missions to address the related science questions.

#### Recent Achievements

NASA initiated two new science teams in FY 2015 via a competitive solicitation: the multi-sensor land imaging science team and the solar irradiance science team. Other activities included calibration/validation for the SMAP mission.

The NASA Ocean Biology Processing Group developed two independent calibrations of the Suomi NPP Visible Infrared Imaging Radiometer Suite (VIIRS) moderate resolution reflective solar bands using solar diffuser measurements and lunar observations, and implemented a combined solar- and lunar-based calibration to track temporal changes in radiometric response of the instrument. The team has achieved a radiometric stability for the VIIRS on-orbit calibration that is commensurate with those achieved for Sea-viewing Wide Field-of-View Sensor (SeaWiFS) and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS), supporting the incorporation of VIIRS data into the long-term NASA ocean color data record. Case studies have begun to examine the use of multiple satellite sensors in water quality and clarity retrievals using collocated matchups between SeaWiFS, MODIS, and Suomi NPP VIIRS in the Gulf of Mexico.

### OCEAN SURFACE TOPOGRAPHY SCIENCE TEAM (OSTST)

Ocean Surface Topography Science Team (OSTST) uses scientific data from the Ocean Surface Topography Mission (OSTM) and Jason satellites to measure global sea surface height.

# OTHER MISSIONS AND DATA ANALYSIS

### Recent Achievements

The OSTST has made considerable progress in re-processing the joint agency NASA/CNES TOPEX/Poseidon spacecraft and Jason-1 mission data to refine the climate record. Scientists have produced a number of reconstructions of the last century of sea level data using tide gauge records and statistically derived patterns of sea level variability from altimetry. The reconstructions are robust in showing an increase in the rate of sea level rise during the latter half of the 20th century and continuing to the present day.

## EARTH OBSERVATION SYSTEMS (EOS) RESEARCH

Earth Observation Systems (EOS) Research funds science for the EOS missions, currently Terra, Aqua, Aura, Landsat, and ICESat missions. The project competitively selects individual investigators to undertake research projects that analyze data from specific missions. Whereas, overall, the selected activities focus on science data analyses and the development of Earth system data records, including climate data records relevant to NASA's research program, some funded activities continue algorithm improvement and validation for the EOS instrument data products.

### Recent Achievements

Research utilizing the long-term data sets from the EOS missions resulted in many publications and new data products. Several important 2015 publications examined linkages of land cover/land use change practices, the urban environment, and climate change. Research shows that urban areas are becoming more densely populated, and thus the impacts and feedbacks of population increases and land cover/land use change practices in cities require further study. Investigators analyzed the relationship between the progress of accumulated springtime temperatures and satellite observations of landscape greenness in and around 51 cities across the U.S. Great Plains during 2002–2012. Results revealed that urban intensity, as measured by the proportion of impervious to pervious surface area, influences the seasonal progression of landscape greenness differently depending regional climate.

Other studies utilizing data from the Aura instruments showed that the influence of India and southeastern Asia emissions on ozone pollution export to the northwestern Pacific is sizeable, comparable with Chinese emissions in winter, about 50 percent of Chinese emissions in spring and fall, and approximately 20 percent of the emissions in the summer.

## STRATOSPHERIC AEROSOL AND GAS EXPERIMENT III (SAGE-III)

The Stratospheric Aerosol and Gas Experiment III (SAGE-III) will provide global, long-term measurements of key components of Earth's atmosphere. The most important of these are the vertical distribution of aerosols and ozone from the upper troposphere through the stratosphere. In addition, SAGE-III provides unique measurements of temperature in the stratosphere and mesosphere and profiles of trace gases, such as water vapor and nitrogen dioxide, which play significant roles in atmospheric radiative and chemical processes. These measurements are vital inputs to the global scientific community for improved understanding of climate, climate change, and human-induced ozone trends.

To take these measurements, SAGE-III relies upon the flight-proven designs used in the Stratospheric Aerosol Measurement (SAM I) and SAGE-I and -II instruments. NASA will deliver SAGE-III to the ISS aboard a commercial SpaceX flight in 2016.

# OTHER MISSIONS AND DATA ANALYSIS

### Recent Achievements

ESA and Thales Alenia Space, headquartered in France, delivered the Hexapod in February 2015, and the ESA team members supported its integration and test activities. In addition, the project successfully completed the thermal-vacuum testing of the instrument payload. The project has completed nearly all assembly, integration, and test activities, and is preparing the SAGE-III hardware for shipment to the launch site. NASA moved the SpaceX-10 launch date from February 2016 to June 2016 due to the SpaceX-7 launch failure.

## SUSTAINABLE LAND IMAGING

The Sustainable Land Imaging (SLI) program enables the development of a multi-decade, spaceborne system that will provide U.S. users with high quality, global, land-imaging measurements. These measurements will be compatible with the existing 43-year Landsat record and will address near- and longer-term issues of continuity risk. They will also evolve flexibly and responsibly through investment in, and introduction of, new sensor and system technologies. Under the SLI framework, NASA will maintain responsibility for developing, launching, and initial checkout of space systems. The United States Geological Survey (USGS) will be responsible for collecting and documenting user requirements, developing the associated ground systems, operating the on-orbit spacecraft, and collecting, calibrating, archiving, processing, and distributing SLI system data to users.

Through the implementation of SLI technology activities, NASA will enable new SLI measurement technologies, capabilities and architectures. SLI technology activities will also reduce the risk, cost, size, volume, mass, and development time for next generation SLI instruments, while still meeting the SLI program requirements. NASA will solicit (through ROSES) instrument and subsystem developments coordinated with the Landsat science community. NASA anticipates the first awards will start in late FY 2016 or early FY 2017. NASA intends that approximately 80 percent of the awards will focus on systems level developments (instruments), leading to engineering models appropriate for the next Landsat (10) or a future Earth Venture Mission, Instrument, or Suborbital. The remaining approximately 20 percent of the awards will be for subsystems (components) for Landsat 11 and beyond.

To minimize the risk of gaps while taking advantage of cost savings and capability enhancements owing to the technology development activity outlined above, the Administration will make key strategic decisions on Landsat 10 payload/instrument approaches by the end of the decade, with the goal of beginning development of the Landsat 10 mission prior to the launch of Landsat 9.

Additional SLI activities support efforts to minimize costs and maximize the overall utility for U.S. users by engaging responsibly with international partners to ensure access to high-quality data and fusion of those measurements with those from the U.S. Landsat missions. In particular, NASA and USGS conducted pre-launch cross-calibration investigations with the European developers of the Sentinel 2A/B land imaging system, ensuring uniform calibration of both Landsat 8 and Sentinel 2A/B instruments to the same standards. The USGS, supported by NASA and other agencies, is serving as the primary U.S. Government point of contact to ensure access to, and archiving of, Sentinel 2 data products for U.S. research and operational users.

# OTHER MISSIONS AND DATA ANALYSIS

### Recent Achievements

In FY 2015, NASA selected several research investigations aimed at developing and testing merged products derived from multiple land imaging systems (such as Landsat 8 and Sentinel 2A). USGS continued the development of new science products derived from Landsat data. These products remove the burden of processing from the end user, support modeling and decision support for land management, enable scientific assessments of land surface change, and enable future projections of landscape state and condition.

## RADIATION BUDGET INSTRUMENT (RBI)

RBI will fly on the Joint Polar Satellite System 2 (JPSS-2) mission planned for launch in November 2021, and will extend the unique global climate measurements of the Earth's radiation budget provided by the Clouds and the Earth's Radiant Energy Systems (CERES) instruments since 1998. Observations from RBI will help measure the effect of clouds on the Earth's energy balance, which strongly influences both weather and climate. Long-term satellite data from RBI will help scientists and researchers understand the links between the Earth's incoming and outgoing energy, and properties of the atmosphere that affect it. The data from RBI will provide fundamental inputs to extended range (10-day or longer) weather forecasting, and will be used to develop a quantitative understanding of the links between Earth's radiation budget and the properties of the atmosphere and surface that define that budget.

### Recent Achievements

The RBI completed its SRR and its Integrated Baseline Review (IBR).

## EARTH FROM ISS

NASA's ISS program sponsored the development of several earth science instruments for the ISS. The Earth from ISS project will ensure the appropriate processing of data and its availability to the earth science research community from the data collected by these instruments. This project will invest in algorithm development, data production, and distribution, as well as data analysis and modeling for the currently planned ISS earth science payloads.

ISS-RapidScat, installed on ISS in October 2014, is a space-based scatterometer that replaces the inoperable SeaWinds payload aboard the QuikSCAT satellite. Scatterometers are radar instruments that measure wind speed and direction over the ocean, and are useful for weather forecasting, hurricane monitoring, and observations of large-scale climate phenomena, such as El Niño. The ISS RapidScat instrument enhances measurements from other international scatterometers by crosschecking their data, and demonstrates a unique way to replace an instrument aboard an aging satellite. The RapidScat instrument used spare parts from QuikSCAT to provide a demonstration of the earth observing capabilities of the ISS as a platform for Earth observations.

The ISS Cloud Aerosol Transport System (CATS) instrument launched on January 10, 2015 aboard a SpaceX Dragon spacecraft, and astronauts installed it on ISS on January 23, 2015. CATS is generating data useful for improving our understanding of aerosol and cloud properties and interactions. In addition, the project will use data from CATS to advance operational aerosol forecast models to improve air quality prediction and monitoring and to improve hazard-warning capabilities for natural events (e.g., dust storms and volcanic eruptions).

# OTHER MISSIONS AND DATA ANALYSIS

The ISS Lightning Imaging Sensor (LIS) will make space-based lightning observations, and will provide important continuity in the lightning data record obtained by the TRMM spacecraft (1997–2015). LIS observations continue to support and used by the global scientific research community across a wide range of disciplines that include weather and extreme storms, climate studies, atmospheric chemistry, and lightning physics. NASA plans to launch ISS-LIS in February 2016.

### Recent Achievements

Scientists successfully calibrated ISS-RapidScat against QuikSCAT, and it is successfully fulfilling its role as a primary cross-calibration instrument across the international constellation of scatterometers. RapidScat data are used in near-real time by operational agencies in the U.S. and Europe to monitor high winds at sea (e.g. hurricanes), allowing them to provide life-saving warnings to mariners. RapidScat data are also fulfilling the scientific challenge of describing for the first time the diurnal (daily) variation of winds at sea. This is a consequence of the unique orbit of this scatterometer, enabled by its installation on ISS.

## TOTAL SOLAR IRRADIANCE SENSOR-2 (TSIS-2)

TSIS-2 will be the follow-on instrument to the TSIS-1 instrument. The TSIS-2 instrument will maintain and extend the measurements of total solar irradiance and spectral solar irradiance provided by TSIS-1. TSIS-2 is a mission of opportunity, to be ready for integration onto a host spacecraft by January 2020. The TSIS-2 project will begin formulation in FY 2017.

## EARTH RADIATION BUDGET SCIENCE

The goal of the Earth Radiation Budget Science (ERBS) Project is to produce climate data records of Earth's radiation budget and the associated cloud, aerosol, and surface properties. The project utilizes data from the multiple radiation budget instruments in orbit as well as ancillary measurements to produce data products, which are integrated and self-consistent over the entire suite of radiation budget instruments. In addition to the five currently operating CERES instruments measuring broadband radiative fluxes from the Terra, Aqua, and Suomi NPP platforms, the data products utilize coincident imager measurements from Terra, Aqua, Suomi NPP, and operational geostationary satellite observations. In total, 13 instruments on eight spacecraft produce an accurate and temporally consistent description of the radiation budget, not only at the top of the atmosphere but also at the surface and within the atmosphere.

### Recent Achievements

The ERBS team continues to produce the most accurate, continuous, long-term Earth Radiation Budget climate data record, and is preparing to incorporate data from instruments planned to launch in the near future, such as the CERES flight model 6 scheduled for launch on NOAA's JPSS-1 in early 2017.

## OZONE MAPPING AND PROFILER SUITE LIMB SOUNDER (OMPS-L)

The advanced Ozone Mapping and Profiler Suite (OMPS) tracks the health of the ozone layer and measures the concentration of ozone in the Earth's atmosphere. OMPS consists of three spectrometers: a downward-looking nadir mapper, nadir profiler, and limb profiler. The entire OMPS suite currently operates on the Suomi NPP spacecraft, and to ensure data continuity, a copy of this suite will fly on

# OTHER MISSIONS AND DATA ANALYSIS

NOAA's JPSS-2 mission, planned for launch in 2021. NASA is responsible for providing the OMPS-Limb profiler for integration on the OMPS instrument.

### Recent Achievements

The project completed the design for the OMPS-Limb subassembly sensor, and completed the alignment of the flight camera and telescope housings.

## TOTAL SOLAR IRRADIANCE SENSOR-1 (TSIS-1)

The TSIS-1 mission will provide absolute measurements of the total solar irradiance (TSI) and spectral solar irradiance (SSI), important for accurate scientific models of climate change and solar variability. TSIS is comprised of two instruments, the Total Irradiance Monitor (TIM), and the Spectral Irradiance Monitor (SIM). Both instruments are in storage at the University of Colorado's Laboratory for Atmospheric and Space Physics awaiting flight. Currently, the data from an earlier NASA-managed TIM instrument, flying on the aging SORCE spacecraft, launched in 2003, provides the TSI data record as part of an unbroken 35-year long data record. The Total Solar Irradiance Calibration Transfer Experiment (TCTE) instrument, a joint mission with NOAA and the U.S. Air Force, launched in 2013 and currently augments the data record. The TSIS-1 project transferred fully to NASA in FY 2016 and it is on the manifest for installation on the ISS in FY 2017 in time to overlap with the TCTE mission in order to maintain continuity of the solar irradiance measurement.

## SENTINEL-6

The Sentinel-6 missions are part of the ESA Copernicus Earth observation program. Two spacecraft, Sentinel-6A and -6B, will continue ocean altimetry measurements beyond the Jason-3 mission that NOAA is pursuing in partnership with the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and ESA. NASA will contribute the Advanced Microwave Radiometer, the Global Positioning System (GPS) Radio Occultation, the LRA, and the launch vehicle for both spacecraft. NASA's Sentinel-6 project will begin formulation in FY 2016.

### Recent Achievements

NASA assigned implementation of this project to JPL and the project-initiated discussions with EUMETSAT and ESA on a partnership agreement.

## PRE-AEROSOL, CLOUDS, AND OCEAN ECOSYSTEM (PACE)

The Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) mission will make global ocean color measurements essential for understanding the carbon cycle and how it both affects and is affected by climate change, along with polarimetry measurements to provide extended data records on clouds and aerosols. New and continuing global observations of ocean ecology, biology, and chemistry are required to quantify aquatic carbon storage and ecosystem function in response to human activities and natural events. The PACE mission will serve to make these measurements until the more advanced Aerosol, Cloud, and Ecosystems (ACE) mission (recommended by the National Academies Decadal Survey for its Tier 2 mission set) is ready.

# OTHER MISSIONS AND DATA ANALYSIS

### Recent Achievements

PACE is in the pre-formulation phase, and has conducted multiple architecture and trade studies. During FY 2015, the project examined alternatives for its primary instrument (an ocean color spectrometer) and for the highly desired secondary instrument (a polarimeter). Alternatives for the spacecraft bus architecture, and for the launch vehicle were (and continue to be) studied. The project is using a design-to-cost approach for evaluating architectures and designs for all the major subsystems and keeping the overall mission within a defined cost cap. The mission will enter the formulation phase in FY 2016.

## CLARREO PATHFINDER

The 2007 National Academies Earth Science decadal survey recommended the Climate Absolute Radiance and Refractivity Observatory (CLARREO) mission as a Tier 1 mission that would be a key component of the future climate observing system. The CLARREO Pathfinder mission will demonstrate essential measurement technologies of the full CLARREO mission; validate the high accuracy radiometry required for long-term climate studies in support of other decadal survey and land imaging missions; and initiate measurements that will benchmark the shortwave reflectance and infrared climate record. NASA plans to host the two CLARREO Pathfinder instruments, Reflected Solar (RS), and Infrared (IR) spectrometers, on the ISS in late FY 2019.

### Recent Achievements

The project began formulation activities in FY 2016 in preparation for the Mission Design Review.

## LANDSAT 9

Landsat 9 is the first flight mission established under the SLI program. The Landsat 9 project is the successor mission to Landsat 8. Landsat satellites have continuously acquired multispectral images of the global land surface since the launch of Landsat 1 in 1972. The Landsat data archive constitutes the longest continuous moderate-resolution record of the global land surface as viewed from space. The Landsat 9 mission objective is to extend the ability to detect and quantitatively characterize changes on the global land surface, at a scale where scientists can differentiate natural and human-induced causes of change. Landsat 9 will fly near-identical copies of the OLI and Thermal Infrared Sensor (TIRS) instruments on Landsat 8. The project will upgrade the TIRS instrument to a risk class B implementation to increase its design life from 3 years to 5 years and to fix small design flaws in the Landsat 8 TIRS design. The project plans no changes to OLI. Landsat 8 designs and subsystems will be used to the extent possible to minimize cost, schedule, and risk. Landsat 9 data will be fully compatible with Landsat 8 processing systems and standard measurement products.

### Recent Achievements

NASA and USGS established their Landsat 9 project activities in 2015. GSFC established the Landsat 9 Project Office in March 2015. During FY 2015, the project began procurement activities for OLI-2 and provided a justification for a sole source contract with Ball Aerospace & Technologies, Inc. (BATC) to provide a copy of the original OLI design that BATC provided for Landsat 8. The TIRS-2 instrument project, an in-house development at GSFC, began trade studies to upgrade reliability and to fix the small on-orbit issues with the Landsat 8 TIRS design. The TIRS-2 instrument team also initiated procurement activities for long-lead parts. The Landsat 9 project office reviewed and incorporated lessons learned from

# OTHER MISSIONS AND DATA ANALYSIS

Landsat 8 at the project, instrument, spacecraft system and subsystems, and ground system levels. USGS established its Landsat 9 ground system project at the USGS Earth Resources Observation and Science (EROS) Center in Sioux Falls, South Dakota in March 2015.

## DECADAL SURVEY MISSIONS

The Decadal Survey project contains missions recommended by the National Academies Earth Science decadal survey, as well as a variety of climate change missions. All the missions within this project are in a pre-formulation phase conducting mission concept studies. The current portfolio of missions under study includes:

- CLARREO;
- Active Sensing of CO2 Emissions over Nights, Days, and Seasons (ASCENDS);
- GEOstationary Coastal and Air Pollution Events (GEO-CAPE);
- ACE; and
- Hyperspectral Infrared Imager (HyspIRI).

### Recent Achievements

Mission teams continue to make progress in requirements refinement and modeling, instrument concept and technology maturation, and algorithm development. ACE, CLARREO, GEO-CAPE, and HyspIRI participated in airborne campaigns in 2015 to demonstrate measurement techniques and make further progress in algorithm development.

## EARTH SCIENCE PROGRAM MANAGEMENT

The Earth Science Program Management budget supports critical flight project management functions executed by the ESM Program Office at GSFC, the Earth System Science Pathfinder Program Office at LaRC and the Earth Science Flight Project Office at JPL. This budget also supports:

- The GSFC conjunction assessment risk analysis function, which determines maneuvers required to avoid potential collisions between spacecraft and to avoid debris;
- The technical and management support for the international Committee on Earth Observation Satellites, which coordinates civil space-borne observations of Earth. Participating agencies strive to enhance international coordination and data exchange and to optimize societal benefit;
- Senior Review Board teams, who conduct independent reviews of the various flight projects in Earth Science;
- Earth Science division communications and public engagement activities.

## PRECIPITATION SCIENCE TEAM

The Precipitation Science Team carries out investigations of precipitation using measurements from, but not limited to, TRMM launched in November 1997 and nearing its end of life, the GPM Core Observatory launched February 2014, and GPM mission constellation partner spacecraft (partners include NOAA, DoD, CNES, JAXA, and EUMETSAT). This program supports scientific investigations in three research categories:

# OTHER MISSIONS AND DATA ANALYSIS

- Development, evaluation, and validation of TRMM and GPM retrieval algorithms;
- Development of methodologies for improved application of satellite measurements; and
- Use of satellite and ground measurements for physical process studies to gain a better understanding of the global water cycle, climate, and weather and concomitant improvements in numerical models on cloud resolving to climate scales.

### Recent Achievements

Throughout the TRMM era, and now extending into the GPM era, space agencies around the world have launched an increasingly rich collection of passive microwave sensors in low Earth orbits that provide additional sources of satellite precipitation estimates. NASA-supported scientists have introduced the key concept of a consistently calibrated multi-satellite product that makes it possible for a wide range of users to take advantage of these data without needing expert knowledge of all the sensors, algorithms, and viewing geometries. The NASA-supported work includes the TMPA and the Integrated Multi-satellite Retrievals for GPM (IMERG). In each case, the precipitation estimates that are considered the most trustworthy among those currently available are used to calibrate estimates made from other satellite platforms, and information from rain gauge analyses are combined into a single surface rainfall estimate over most of the globe. TMPA and IMERG are the most requested and downloaded products from the NASA Precipitation Processing System (PPS) website and are freely available to researchers from around the world. Scientists use this data extensively for weather and climate studies and many applications including the study of floods, droughts, and landslides.

## OCEAN WINDS SCIENCE TEAM

Ocean Winds Science Team (OWST) uses scientific data received from the QuikSCAT satellite, RapidScat instrument, and other international missions, which measure ocean surface winds by sensing ripples caused by winds at the ocean’s surface. From this data, scientists can compute wind speed and direction thus acquiring global observations of surface wind velocity each day. The sparse wind data from ships and buoys serve to calibrate the satellite data.

### Recent Achievements

A climate record task team is providing NASA with ways and means to integrate the various data streams into a continuing wind record with documented characteristics (e.g., averages, trends, noise levels, and uncertainties). This ongoing process will guide the team through the process of calibration and validation of data sets and their incorporation into the wind climate record.

## LAND COVER PROJECT SCIENCE OFFICE

The Land Cover Project Science Office (LCPSO) maintains over 40 years of calibration records for the Landsat 1 through Landsat 8 series of satellites. The office also provides community software tools to make it easier for users to work with this data. In collaboration with USGS, LCPSO supports improvements in the Landsat 7 long-term acquisition plan and provision of preprocessed data sets for land-cover change analysis, and facilitates use of international data sets for improved land cover monitoring.

# OTHER MISSIONS AND DATA ANALYSIS

### Recent Achievements

A recent focus of the LCPSO has been to prepare the U.S. land cover research community for the integration of European Sentinel-1 and Sentinel-2 datasets into land monitoring activities. The LCPSO has developed algorithms and software to generate consistent reflectance measurements from the combined Sentinel-2/Landsat satellite series. The LCPSO has also continued to maintain the website (http://cad4nasa.gsfc.nasa.gov/) that allows NASA-funded investigators convenient access to commercial imagery procured by the National Geospatial-Intelligence Agency.

## OCEAN SALINITY SCIENCE TEAM

The NASA OSST supports the development and construction of surface salinity products from L-Band microwave radiometers such as Aquarius, SMAP, and data sets of opportunity such as the ESA Soil Moisture and Ocean Salinity (SMOS) mission. The team also seeks to understand upper-ocean processes that impact variability of surface salinity in order to improve interpretation of the space-based salinity products. The team plans to produce a SMAP salinity product that is consistent with the Aquarius salinity product, which ended in June 2015.

### Recent Achievements

The OSST is overseeing the production of the final Aquarius salinity product that will include the best available corrections and ancillary fields. This will stand as the most precise space-based salinity product, extending from September 2011 to June 2015. The team will extend this record by using data from the SMAP mission. The OSST is engaged in a yearlong field observation project in 2016-2017. Scientists expect that the results from this project, when combined with previous field campaign observations, will improve modeling of the ocean branch of the global water cycle.

# Operating Missions

## SOIL MOISTURE ACTIVE AND PASSIVE (SMAP)

The SMAP mission will provide a capability for global mapping of soil moisture with unprecedented accuracy, resolution, and coverage. The SMAP measurement system consists of a radiometer (passive) instrument and a synthetic aperture radar (active) instrument operating with multiple polarizations in the L-band range. The radar and radiometer share a single feed and deployable six-meter reflector antenna system.

Scientific understanding of how climate change may affect water supply and food production is crucial for policy makers. Uncertainty in current climate models result in disagreement on whether there will be more or less water regionally compared to today. SMAP data will help bring climate models into agreement on future trends in water resource availability.

For more information, go to http://smap.jpl.nasa.gov.

# OTHER MISSIONS AND DATA ANALYSIS

### Recent Achievements

SMAP launched January 31, 2015 and successfully completed on-orbit checkout May 6, 2015, following the nominal deployment and spin-up of its six-meter mesh antenna. Unfortunately, the radar instrument, which began regular operations on April 13, stopped transmitting July 7 due to an anomaly that is currently under investigation. NASA has formed a Mishap Investigation Board, which will issue its report in the first half of 2016. Since the loss of the radar will reduce the spatial resolution the mission intended to achieve, the mission science team is working to recover some of the resolution by enhancing the radiometer data with available coincident radar data from other missions such as ESA's Sentinel 1. Even without the radar, the SMAP data have already been useful in applications that support events such as the October 2015 flooding in South Carolina.

## TROPICAL RAINFALL MEASURING MISSION (TRMM)

The TRMM mission measured precipitation, clouds, and lightning over tropical and subtropical regions and extended our knowledge about how the energy associated with rainfall interacts with other aspects of the global climate. The TRMM sensor suite provided a three-dimensional map of storm structure, yielding information on rain intensity and distribution. TRMM launched in 1997 as a joint mission with Japan. TRMM exhausted its orbit maintenance fuel in July 2014. The project passivated the spacecraft in April 2015 and it re-entered the Earth's atmosphere on June 17, 2015. Any remnants that did not dissipate in the atmosphere fell harmlessly to Earth in the southern Indian Ocean. The joint team continued to collect science data through most of TRMM's orbital descent.

### Recent Achievements

The project completed and delivered the final TRMM mission report, and dismantled the mission operations center. The TRMM precipitation dataset will receive its final re-processing following an algorithm update coordinated with the follow-on GPM. This will enable a smooth transition of the precipitation climate record to GPM, and will create a multi-decadal data record. The final TRMM dataset will be available to the science community in mid-2017.

## DEEP SPACE CLIMATE OBSERVATORY

The Deep Space Climate Observatory (DSCOVR) mission is a multi-agency (NOAA, U.S. Air Force [USAF], and NASA) mission with the primary goal of making unique space weather measurements from the Lagrange point L1. Lagrange point L1 is on the direct line between Earth and the Sun and provides about a 45-minute early warning for adverse space weather events. NASA provided the two Earth-observing instruments, the Earth Poly-Chromatic Imaging Camera (EPIC) and the National Institute of Standards and Technology (NIST) Advanced Radiometer (NISTAR), to the DSCOVR satellite. The agencies launched the satellite on February 11, 2015 aboard a USAF-provided SpaceX Falcon 9 launch vehicle out of Cape Canaveral, FL. NASA is collecting the data from EPIC and NISTAR, and has developed and implemented the necessary algorithms to enable the "Earth at noon" images from the satellite. NASA will archive and publicly disseminate the data following calibration and validation activities.

# OTHER MISSIONS AND DATA ANALYSIS

### Recent Achievements

The project completed preliminary EPIC and NISTAR instrument calibrations, demonstrating that these instruments will meet their Level 1 science requirements. NASA successfully transitioned the operations of the DSCOVR spacecraft and all of its instruments to NOAA. NASA released a web site publicly distributing all the color images of Earth collected by the EPIC on October 19, 2015. For more information, go to http://epic.gsfc.nasa.gov.

## GLOBAL PRECIPITATION MEASUREMENT (GPM)

The GPM mission will advance the measurement of global precipitation. A joint mission with JAXA, GPM will provide the first opportunity to calibrate measurements of global precipitation (including the distribution, amount, rate, and associated heat release) across tropical, mid-latitude, and polar regions.

The GPM mission has several scientific objectives:

- Advance precipitation measurement capability from space through combined use of active and passive remote-sensing techniques;
- Advance understanding of global water/energy cycle variability and fresh water availability;
- Improve climate prediction by providing the foundation for better understanding of surface water fluxes, soil moisture storage, cloud/precipitation microphysics, and latent heat release in Earth's atmosphere;
- Advance numerical weather prediction skills through more accurate and frequent measurements of instantaneous rain rates; and
- Improve high-impact natural hazard event (flood and drought, landslide, and hurricanes) and fresh water-resource prediction capabilities through better temporal sampling and wider spatial coverage of high-resolution precipitation measurements.

### Recent Achievements

Well into its second year of operations, GPM continues to perform exceptionally well. The GPM Microwave Imager (GMI) is the best-calibrated conically scanning microwave precipitation radiometer among approximately 10 precipitation radiometers currently in orbit. GPM continues to observe hurricanes, cyclones, and typhoons all over the world and scientists use GMI images to fix eye wall locations by operational agencies (with over 100,000 hits per month on the NRL Tropical Cyclone webpage). During the winter season, GPM observed many snowfall events, although much work remains to validate the data. With the recent launch of SMAP, scientists have begun to investigate the links between precipitation and soil moisture with an initial focus on the heavy rains and flooding in South Carolina during the storms of September 26-October 5, 2015.

## LANDSAT 8

Landsat 8 is the most recent in the Landsat series of satellites that have been continuously observing Earth's land surfaces by recording data since 1972. This data is a key tool for assessing climate change impacts. The data has contributed to the improvement of human and biodiversity health, energy and water management, urban planning, disaster recovery, and agriculture monitoring. USGS performs mission operations for Landsat 8, but NASA will provide science activities in support of the USGS and the Landsat Science Team for the period of prime mission operations.

### Recent Achievements

NASA continues to manage the ongoing technical issues with the TIRS, one of two sensors flown aboard the spacecraft. One issue results from stray light in the TIRS telescope, which causes uncertainty up to several degrees in certain situations. NASA implemented a bias correction for data processing, and continues to investigate more sophisticated methods of reducing uncertainty. TIRS also suffered an anomaly in the electronics controlling a mirror that transitions the sensor view from the Earth to deep space for calibration. The instrument is now operating using redundant electronics (Side B). NASA continues to monitor the performance on Side B, and to develop alternative modes of operating TIRS in the event of a reoccurring anomaly.

## OCEAN SURFACE TOPOGRAPHY MISSION (OSTM)

OSTM, or Jason-2, measures sea surface height and enables scientists to assess climate variability and change, and water and energy cycles. This mission is the third in a series of ocean surface topography missions (following Jason-1 and TOPEX/Poseidon) and is the only one currently operating. OSTM is a joint mission with NOAA, CNES, and the European Organisation for the Exploitation of Meteorological Satellites. OSTM will provide cross-calibration with Jason-3 (launching in 2016). It will also serve to increase the spatial and temporal resolution of altimetry measurements in 2017 when OSTM is maneuvered into the interweaved five-day repeat orbit that was previously occupied by Jason-1. The 2015 Earth Science senior review endorsed the OSTM mission for continued operations through 2017 and preliminarily through 2019. The next senior review will occur in 2017, and will re-evaluate the OSTM mission extension in terms of scientific value, national interest, technical performance, and proposed cost in relation to NASA Earth Science strategic plans.

### Recent Achievements

The results from OSTM and its predecessor missions continue to flood professional journals and the general media at the rate of about 200 publications per year. These illustrate the continuous use of OSTM data among the Earth science community. With the 23-year record of continuous altimetry data, the mission's science team has made extensive progress in the study of decades-long changes in the circulation of the South Pacific as well as the North Atlantic. OSTM is now monitoring the El Nino that is developing this year.

## SUOMI NATIONAL POLAR-ORBITING PARTNERSHIP (SUOMI NPP)

Suomi NPP successfully launched in 2011, and transitioned to routine operations under NOAA management in 2013. The five instruments on Suomi NPP provide visible and infrared multi-spectral global imagery, atmospheric temperature and moisture profiles, total ozone and stratospheric ozone profiles, and measurements of Earth's radiation balance. In addition to a wide range of applications studies, the NASA science focus areas served by Suomi NPP include atmospheric composition, climate variability and change, carbon cycle, ecosystems, water and energy cycles, and weather. NASA and NOAA continue to collaborate during the mission's five-year prime operations phase to ensure meeting the shared objectives of both agencies.

# OTHER MISSIONS AND DATA ANALYSIS

### Recent Achievements

The Suomi NPP mission has met its minimum success criteria, and is on track to achieve full mission success at the end of its prime operations phase in late 2016. Suomi NPP data is publicly available from NOAA, and the National Weather Service uses it in support of the operational weather forecast system. Research data products produced by NASA's Suomi NPP science team are also publicly available, and support NASA's continuity objectives for the mission.

## TERRA

Terra is one of the EOS flagship missions. It enables a wide range of interdisciplinary studies of atmospheric composition, carbon cycle, ecosystems, biogeochemistry, climate variability and change, water and energy cycles, and weather. Terra, launched in 1999, is a joint mission with Japan and Canada. The 2015 Earth Science senior review endorsed the Terra mission for continued operations through 2017 and preliminarily through 2019. The next senior review will occur in 2017, and will re-evaluate the Terra mission extension in terms of scientific value, national interest, technical performance, and proposed cost in relation to NASA Earth Science strategic plans.

### Recent Achievements

The Terra mission has now provided more than 15 years of continuous data collection, providing fundamental observations of the Earth's climate system, high-impact events, and adding value to other satellite missions and field campaigns. The spacecraft platform and five sensors are all fully functional (with the exception of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Shortwave Infrared (SWIR) bands), and the mission is expected to continue operations for the near future. Recent data product accomplishments include the ASTER-based high-resolution global topographic dataset, near-real-time aerosol products, a large statistical database of wildfire smoke and volcanic aerosol plumes from the Multi-angle Imaging SpectroRadiometer (MISR), and several major calibration updates to the MODIS dataset that improves ocean color, land vegetation, aerosol, and cloud science. The number of peer-reviewed papers from the Terra mission exceeds 11,000.

## AQUA

Aqua, another of the Earth Observing System flagship missions, also operates in the afternoon constellation of satellites, known as the A-Train. Aqua improves our understanding of Earth's water cycle and the intricacies of the climate system by monitoring atmospheric, land, ocean, and ice variables. Aqua, launched in 2002, is a joint mission with Brazil and Japan. Four of its Earth observing instruments – the Atmospheric Infrared Sounder (AIRS), the Advanced Microwave Sounding Unit (AMSU), CERES, and MODIS – continue to collect valuable data about the atmosphere, oceans, land, and ice, and these data are widely used by the science and applications communities. The 2015 Earth Science senior review endorsed the Aqua mission for continued operations through 2017 and preliminarily through 2019. The next senior review will occur in 2017, and will re-evaluate the Aqua mission extension in terms of scientific value, national interest, technical performance, and proposed cost in relation to NASA Earth Science strategic plans.

# OTHER MISSIONS AND DATA ANALYSIS

### Recent Achievements

The Aqua spacecraft is still going strong, well past its six-year design lifetime. AIRS data recently quantified marked decreases in Northern Hemisphere atmospheric carbon monoxide. Advanced Microwave Scanning Radiometer - Earth Observing System (AMSIR-E) data showed a 20 to 30-day periodicity in the atmospheric general circulation of the Southern Hemisphere. Aqua data identified shortcomings in the representation of cloud radiative effects in a major climate model through comparisons with CERES radiative fluxes; and MODIS data mapped extremely large interannual variability in melt over the Greenland ice sheet. The rate of science publications incorporating Aqua data is now over 1,000 per year.

## AURA

The Aura mission enables study of atmospheric composition, climate variability, and weather by measuring atmospheric chemical composition, tropospheric/stratospheric exchange of energy and chemicals, chemistry-climate interactions, and air quality. Launched in 2004, Aura is also part of the A-Train. It is a joint mission with the Netherlands, Finland, and the United Kingdom. Three of Aura's four instruments are operational: the Microwave Limb Sounder (MLS), the Ozone Monitoring Instrument (OMI), and the Tropospheric Emission Spectrometer (TES). Additional measurements include clouds, aerosols, solar spectral irradiance, and water vapor. The 2015 Earth Science senior review endorsed the Aura mission for continued operations through 2017 and preliminarily through 2019. The next senior review will occur in 2017, and will re-evaluate the Aura mission extension in terms of scientific value, national interest, technical performance, and proposed cost in relation to NASA Earth Science strategic plans.

### Recent Achievements

The broad user community continues to draw on the rich Aura data record to develop and expand understanding of the Earth system, as reflected in the strong publication record (459 out of 1589 Aura-related journal articles have been published during the past two years) and the increasing number of downloads from the data centers. The Aura spacecraft is operating very well, with primary subsystems still in use where redundancy is available. MLS is performing very well; scientists observe all products daily, with the exception of the hydroxyl radical (OH) and upper stratospheric hydrochloric acid (HCl). Since the loss of the ESA Envisat in 2012, most Aura MLS measurements are unique. OMI provides high quality column measurements of ozone and tropospheric pollutants, obtaining full global coverage within two days despite limitation to its wide swath. The TES observing strategy focuses on special observations to obtain maximum science benefit in light of signs of aging.

## SOLAR RADIATION AND CLIMATE EXPERIMENT (SORCE)

The SORCE mission measures the total and spectral solar irradiance incident at the top of Earth's atmosphere. SORCE measurements of incoming X-ray, ultraviolet, visible, near infrared, and total solar radiation help researchers to address long-term climate change, natural variability and enhanced climate prediction, and atmospheric ozone and ultraviolet-B radiation. These measurements are critical to studies of the Sun, its effect on the Earth system, and its influence on humankind. SORCE, launched in 2003, is in extended operations. The 2015 Earth Science senior review endorsed the SORCE mission for continued operations through 2017 and preliminarily through 2019, but it recognized that the satellite's aging batteries were highly degraded and that it might not survive past 2017. The next senior review will occur in 2017, and will re-evaluate the SORCE mission extension in terms of scientific value, national interest, technical performance, and proposed cost in relation to NASA Earth Science strategic plans.

### Recent Achievements

SORCE has played a key role in maintaining the continuity of the long-term solar irradiance time series, and NASA expects to transfer the total solar irradiance calibration to the follow-on TSIS mission when it becomes operational. Recent mission highlights are the critical review of the solar spectral irradiance measurements and solar cycle variability results by an independent panel in September 2014, and determination that solar cycle 24 variability is about half as much as the variability during the past few 11-year solar cycles.

## EARTH OBSERVING-1 (EO-1)

The Earth Observing-1 (EO-1) satellite is an advanced land-imaging mission with relevance to various areas of earth science, including carbon cycle, ecosystems, biogeochemistry, and Earth surface and interior. EO-1, launched in 2000, is in extended operations. EO-1 simultaneously acquires 30-meter spatial resolution data from two instruments: Advanced Land Imager (ALI) and Hyperion. EO-1 is a targeting system that is capable of imaging any particular Earth location each day, up to five times every 16 days. This capability has proven to be useful for rapid response monitoring of disasters and specific events. The 2015 Earth Science senior review endorsed the EO-1 mission for continued operations through 2016 only. Based on orbit predictions (the EO-1 satellite has been out of fuel for orbit maintenance since 2011), NASA has determined that operations beyond 2016 would not be of sufficient quality for Earth imaging due to low sun angle. NASA plans to decommission the EO-1 mission on September 30, 2016. Mission closeout, final reporting, and final processing and documentation of the archival science dataset will occur in FY 2017.

### Recent Achievements

At this time last year, NASA planned to decommission the mission in October 2015, but new studies on the orbit degradation demonstrated that it was not as fast as projected, enabling one final mission extension to September 2016. Accordingly, the mission continued to support disaster response, as well as algorithm development for future hyperspectral imaging missions.

# EARTH SYSTEM SCIENCE PATHFINDER

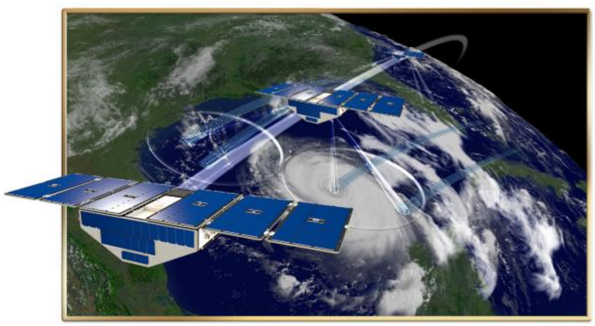
## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Venture Class Missions | 169.1 | -- | **194.3** | 199.6 | 174.7 | 184.3 | 199.9 |
| Other Missions and Data Analysis | 54.6 | -- | **101.7** | 49.0 | 42.0 | 43.5 | 45.2 |
| **Total Budget** | **223.8** | -- | **296.0** | **248.6** | **216.7** | **227.8** | **245.1** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*



**CYGNSS consists of a constellation of eight micro-satellites, each carrying a four-channel radar receiver that measures GPS navigation signals scattered by the ocean surface. The radars will measure hurricane inner core surface winds with high temporal resolution, under all precipitating conditions, and over the full dynamic range of wind speeds.**

The Earth System Science Pathfinder (ESSP) program provides frequent, regular, competitively selected Earth science research opportunities that accommodate new and emerging scientific priorities and measurement capabilities. This results in a series of relatively low-cost, small-sized investigations and missions. Principal investigators whose scientific objectives support a variety of studies lead these missions, including studies of the atmosphere, oceans, land surface, polar ice regions, or solid Earth.

ESSP projects include space missions and remote sensing instruments for space-based missions of opportunity or extended duration airborne science missions. The ESSP program also supports the conduct of science research utilizing data from these missions. ESSP projects often involve partnerships with other U.S. agencies and/or international organizations. This portfolio of missions and investigations provides opportunity for investment in innovative earth science that enhances NASA's capability for better understanding the current state of the Earth system.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Mandatory Budget Authority** | -- | -- | 30.0 | -- | -- | -- | -- |

# EARTH SYSTEM SCIENCE PATHFINDER

ESSP supported in part with mandatory funding. The mandatory investment includes $30 million for a Small Satellite Constellation Initiative.

# VENTURE CLASS MISSIONS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | 169.1 | -- | 194.3 | 199.6 | 174.7 | 184.3 | 199.9 |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**NAAMES (EVS-2) will collect data during ship and aircraft measurement campaigns and combine that data with continuous satellite and ocean sensor readings. Shown here, NASA's C-130H Hercules airborne laboratory begins research flights over the North Atlantic from St. John's, Newfoundland, Canada on Nov. 12, 2015.**

NASA's Earth Venture Class project provides frequent flight opportunities for high-quality earth science investigations that are low cost and that can be developed and flown in five years or less. NASA will select the investigations through open competitions to ensure broad community involvement and encourage innovative approaches. Successful investigations will enhance our capability to understand the current state of the Earth system and to enable continual improvement in the prediction of future changes. Solicitations will alternate between space-borne and airborne/suborbital opportunities.

NASA established the Venture Class project in response to recommendations in the National Academies' report, "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond."

The Earth Venture Class project consists of three different types of activities:

- Earth Venture Suborbital (EVS) are sustained suborbital science investigations. NASA caps each solicitation at $150 million in FY 2014 dollars, and selects multiple investigations within each call, individually capped at $30 million. The EVS solicitations will be made at four-year intervals;
- Earth Venture small Missions (EVM) are small space-based missions. Each solicitation is cost capped at $166 million in FY 2018 dollars. The EVM solicitations will be made at four-year intervals; and
- Earth Venture Instruments (EVI) will fly on space-borne platforms, which NASA will select. Each solicitation is cost capped at $97 million in FY 2018 dollars. NASA will release EVI solicitations at no more than 18-month intervals.

# VENTURE CLASS MISSIONS

## EXPLANATION OF MAJOR CHANGES IN FY 2017

NASA approved the Tropospheric Emissions: Monitoring of Pollution (TEMPO) Instrument to proceed into development. However, there is a delay in TEMPO accommodations activity to allow time to find a suitable host spacecraft. This delay resulted in TEMPO budget changes across almost all years. NASA approved ECOSTRESS to enter the development phase, and the budget now matches project requirements.

## ACHIEVEMENTS IN FY 2015

The Airborne Tropical TRopopause EXperiment (ATTREX) and AirMOSS missions completed data collection and transitioned to scientific analysis; reporting and mission close out activities in FY 2015. NASA selected a sixth Earth Venture Suborbital mission (from the EVI-2 Announcement of Opportunity [AO]), COral Reef Airborne Laboratory (CORAL), to investigate coral reefs.

CYGNSS successfully completed its system integration review and KDP-D. GEDI held a successful system requirements review/mission design review and KDP-B. ECOSTRESS successfully completed its PDR and KDP-B for the Instrument.

The TEMPO instrument converted its development contract with Ball Aerospace and Technologies Corporation from Cost-Plus-Incentive-Fee to Firm-Fixed-Price to reduce the risk of cost growth on the instrument and the impact to the cost cap of the overall mission. In April 2015, NASA confirmed the TEMPO instrument to proceed into development, and the instrument successfully conducted their CDR in July 2015.

NASA released the EVM-2 AO in September 2015 and the EVI-3 solicitation, as the Program Element Appendix (PEA-P), to the Second Stand Alone Missions of Opportunity Notice (SALMON-2) in March 2015.

## WORK IN PROGRESS IN FY 2016

The final competitively selected EVS-1 mission, Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE), finished data collection, and will transition to scientific analysis, reporting, and mission close out activities. The six selected EVS-2 began data collection.

CYGNSS plans to hold an operations readiness review. GEDI will conduct a PDR in Q2 of FY 2016. NASA confirmed the ECOSTRESS Instrument to enter the development phase. The instrument will continue toward the CDR.

TEMPO will conduct the ground system CDR, and plans to complete instrument subsystem development, including critical elements such as the focal plane assembly, spectrometer, and telescope. Integration and test of the instrument will begin in FY 2016.

NASA will announce selections for EVI-3 and EVM-2, and release the EVI-4 AO in FY 2016.

# VENTURE CLASS MISSIONS

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA will continue data collection for the six EVS-2 missions. NASA plans to launch the CYGNSS mission, deliver ECOSTRESS and GEDI to the ISS, and announce the selection of the EVI-4 instrument. TEMPO will complete integration and test of the instrument. The release of the request for proposal (RFP) for hosting the TEMPO instrument will follow instrument delivery.

## Program Elements

### CYGNSS (EVM-1, SELECTED IN 2012)

CYGNSS will make accurate measurements of ocean surface winds throughout the life cycle of tropical storms and hurricanes, leading to better weather forecasting. CYGNSS data will enable scientists to probe from space key air-sea interaction processes that take place near the inner core of the storms, which are rapidly changing, and play large roles in the genesis and intensification of hurricanes. The CYGNSS measurements will also provide information to the hurricane forecast community, potentially enabling better modeling to predict the strength of hurricanes as they develop.

CYGNSS's eight micro-satellite observatories will receive both direct and reflected signals from GPS satellites. The direct GPS signals pinpoint CYGNSS observatory positions, while the reflected signals are indicative of ocean surface roughness. Scientists will use both measurements to derive the critical measurement of wind speed. CYGNSS is currently in development and will launch in FY 2017.

### TEMPO (EVI-1, SELECTED IN 2012)

The TEMPO instrument will measure atmospheric pollution covering most of North America. A commercial communications satellite will host the instrument and launch no later than 2021. On an hourly basis, TEMPO will measure atmospheric pollution from Mexico City to the Canadian tar/oil sands and from the Atlantic to the Pacific. TEMPO will provide measurements that include the key elements of air pollution chemistry, such as ozone and nitrogen dioxide in the lowest part of the atmosphere. Measurements from geostationary orbit will capture the inherent high variability in the daily cycle of emissions and chemistry. Measuring across both time and space will create a revolutionary dataset that provides understanding and improves prediction of air quality and climate forcing.

The project will procure the commercial host spacecraft service through the USAF Space and Missile Systems Center Hosted Payload Solutions contract. In discussions with potential hosts, all identified concerns about the cost impact a late delivery by NASA would have on their spacecraft. In order to avoid the adverse pricing such risk would entail, the TEMPO project will delay the release of the RFP for hosting until after the completion of the instrument, with a projected launch date of 2021.

### ECOSYSTEM SPACEBORNE THERMAL RADIOMETER EXPERIMENT ON SPACE STATION (ECOSTRESS) (EVI-2, SELECTED IN 2014)

ECOSTRESS will observe changes in global vegetation from the ISS. The sensors will give scientists new ways to see how changes in climate or land use change affect forests and ecosystems. ECOSTRESS will use a high-resolution thermal infrared radiometer to measure plant evapotranspiration, the loss of water from growing leaves and evaporation from the soil. These data will reveal how ecosystems change with climate, and provide a critical link between the water cycle and effectiveness of plant growth, both natural and agricultural.

ECOSTRESS will fill a key gap in our observing capability, advance core NASA and societal objectives, and allow NASA to address the following science objectives:

- Identify critical thresholds of water use and water stress in key climate sensitive biomes;
- Detect the timing, location, and predictive factors leading to plant water uptake decline and/or cessation over the daily cycle; and
- Measure agricultural water consumption over the contiguous United States to improve drought estimation accuracy.

## GLOBAL ECOSYSTEM DYNAMICS INVESTIGATION (GEDI) LIDAR (EVI-2, SELECTED IN 2014)

GEDI will use a laser-based system to study a range of climates, including the observation of the forest canopy structure over the tropics, and the tundra in high northern latitudes. This data will help scientists better understand the changes in natural carbon storage within the carbon cycle from both human-influenced activities and natural climate variations. The instrument will be the first to systematically probe the depths of the forests from space by using a lidar instrument from the ISS and will provide a unique 3D view of Earth's forests and provide information about their role in the carbon cycle. The GSFC will build and manage the instrument.

## EARTH VENTURE MANAGEMENT

The Earth Venture Management project provides for the development of AO solicitations and the Technical, Management, and Cost (TMC) evaluations of proposals received in response to the AO solicitations. Additionally, this project supports Common Instrument Interface activities to identify a common set of earth science instrument-to-spacecraft interface guidelines that will improve the likelihood that these instruments can take advantage of future hosted payload opportunities.

In addition, as funding and opportunities permit, NASA supports a small number of technology studies, in an effort to prepare these technologies to compete in future Earth Venture solicitation. In 2015, NASA selected two technology demonstration efforts from EVI-2:

- Green OAWL (GrOAWL): The GrOAWL Demonstrator effort will reduce risk for a potential future ATHENA-OAWL Doppler Wind Lidar mission by providing validated airborne wind profiles measured with a 532-nanometer version of the Optical Autocovariance Wind Lidar instrument. The University of Colorado will manage this work, and Ball Aerospace Corporation will build the GrOAWL instrument.
- Temporal Experiment for Storms and Tropical Systems-Demonstrator (TEMPEST-D): As a technology demonstration effort, a TEMPEST-Demonstrator will reduce the risk for a potential future TEMPEST mission that will provide the first global observations of the time evolution of precipitation. TEMPEST-D provides for a single CubeSat with the required set of five millimeter-wave frequencies from 91 to 183 GHz. TEMPEST-D will validate existing airborne and satellite-based millimeter-wave radiometer data through geolocation, calibration, and intercalibration of

brightness temperatures with the GMI and other available satellite radiometers. The TEMPEST-D team will design, build, qualify, test, and launch a single CubeSat built to meet the TEMPEST mission's radiometer instrument and satellite bus specifications proposed to EVI-2. Colorado State University will lead this work, and JPL will build the 5-frequency radiometer instrument.

## VENTURE CLASS FUTURE MISSIONS

Earth Venture Class Future Mission funding supports future Earth Venture Suborbital, Earth Venture small Missions, and Earth Venture Instruments through AO solicitations.

## EARTH VENTURE SUBORBITAL-1 (EVS-1; SELECTED IN 2010) INVESTIGATIONS INCLUDE:

- AirMOSS addresses the uncertainties in existing estimates by measuring soil moisture in the root zone of representative regions of major North American ecosystems;
- ATTREX studies chemical and physical processes at different times of year from bases in California and Guam;
- CARVE collects an integrated set of data that will provide experimental insights into Arctic carbon cycling, especially the release of the important greenhouse gases such as carbon dioxide and methane;
- Deriving Information on Surface Conditions from COlumn and VERtically Resolved Observations Relevant to Air Quality (DISCOVER-AQ) improves the interpretation of satellite observations to diagnose near-surface conditions relating to air quality; and
- HS3 studies hurricanes in the Atlantic Ocean basin using two NASA Global Hawks flying high above the storms for up to 24 hours.

## EARTH VENTURE SUBORBITAL-2 (EVS-2; SELECTED IN 2014) INVESTIGATIONS INCLUDE:

- Atmospheric Tomography explores the impact of human-produced air pollution on certain greenhouse gases. Airborne instruments will look at how various air pollutants affect atmospheric chemistry (including methane and ozone).
- North Atlantic Aerosols and Marine Ecosystems Study seeks to improve predictions of how ocean ecosystems would change with ocean warming. The mission will study the annual life cycle of phytoplankton, and the impact small airborne particles (composed of material derived from marine organisms) have on climate in the North Atlantic.
- Atmospheric Carbon and Transport-America quantifies the sources of regional carbon dioxide, methane and other gases, and documents how weather systems transport these gases in the atmosphere.
- Observations of Aerosols above Clouds and their Interactions investigates how smoke particles from massive biomass burning in Africa influences cloud cover over the Atlantic. Particles from this seasonal burning interact with permanent stratocumulus "climate radiators," which are critical to the regional and global climate system.

# VENTURE CLASS MISSIONS

- Oceans Melting Greenland project studies the role of warmer, saltier Atlantic Ocean subsurface waters in Greenland glacier melting. The study will help pave the way for improved estimates of future sea level rise by observing changes in glacier melting where ice contacts seawater.
- The CORAL (selected in FY 2015) investigation will analyze the status of coral reefs and predict their future. It will provide the most extensive picture to date of the condition of a large portion of the world's coral reefs.

## Program Schedule

| Date | Significant Event |
|---|---|
| 2016 | EVI-4 (instrument) solicitation released |
| FY 2016 Q2 | GEDI Confirmation Review |
| May 2017 | CYGNSS launch readiness |
| 2017 | EVS-3 (suborbital) solicitation released |
| 2017 | ECOSTRESS Instrument Delivery to ISS |
| 2018 | GEDI Instrument Delivery to ISS |
| 2018 | EVI-5 (instrument) solicitation released |
| 2019 | EVM-3 (mission) solicitation released |
| 2019 | GEDI launch readiness |
| 2019 | ECOSTRESS launch readiness |
| 2020 | EVI-6 (instrument) solicitation released |
| 2021 | TEMPO launch readiness |

## Program Management & Commitments

| Program Element | Provider |
|---|---|
| EVS-2: Atmospheric Tomography Experiment | Provider: Harvard College<br>Lead Center: ARC<br>Performing Center(s): LaRC, ARC, GSFC, AFRC<br>Cost Share Partner(s): NOAA |
| EVS-2: North Atlantic Aerosols and Marine Ecosystems Study | Provider: Oregon State University<br>Lead Center: LaRC<br>Performing Center(s): LaRC, GSFC, ARC<br>Cost Share Partner(s): N/A |

# VENTURE CLASS MISSIONS

| Program Element | Provider |
|---|---|
| EVS-2: Atmospheric Carbon and Transport-America | Provider: Pennsylvania State University<br>Lead Center: LaRC<br>Performing Center(s): LaRC, GSFC, JPL<br>Cost Share Partner(s): N/A |
| EVS-2: Observations of Aerosols above Clouds and their Interactions | Provider: ARC<br>Lead Center: ARC<br>Performing Center(s): ARC, LaRC, GSFC, AFRC, JPL<br>Cost Share Partner(s): University of Namibia |
| EVS-2: Oceans Melting Greenland | Provider: JPL<br>Lead Center: JPL<br>Performing Center(s): JPL, GSFC, AFRC<br>Cost Share Partner(s): Danish National Space Institute, Stockholm University |
| EVS-2: Coral Reef Airborne Laboratory | Provider: Bermuda Institute of Ocean Sciences<br>Lead Center: JPL<br>Performing Center(s): JPL, AFRC<br>Cost Share Partner(s): N/A |
| EVM-1: CYGNSS | Provider: University of Michigan<br>Lead Center: LaRC<br>Performing Center(s): N/A<br>Cost Share Partner(s): N/A |
| EVI-1: TEMPO | Provider: Smithsonian Astrophysical Observatory<br>Lead Center: LaRC<br>Performing Center(s): LaRC, GSFC<br>Cost Share Partner(s): N/A |
| EVI-2: ECOSTRESS | Provider: JPL<br>Lead Center: JPL<br>Performing Center(s): JPL<br>Cost Share Partner(s): USDA |
| EVI-2: GEDI | Provider: University of Maryland<br>Lead Center: GSFC<br>Performing Center(s): GSFC<br>Cost Share Partner(s): N/A |

## Acquisition Strategy

NASA anticipates issuing a solicitation for a Venture Class element at least once a year. NASA will award all Venture Class funds through full and open competition.

# VENTURE CLASS MISSIONS

## MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
|---|---|---|
| CYGNSS: project management, development, integration and mission operations | Southwest Research Institute | San Antonio, TX |
| TEMPO: development of instrument (ultraviolet-visible spectrometer) | Ball Aerospace & Technologies Corp. | Boulder, CO |

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | SRB | Apr 2015 | TEMPO Instrument KDP-C Milestone Review to determine readiness to enter development | TEMPO Instrument approved to enter development | Jun 2015 |
| Perform-ance | SRB | Jun 2015 | TEMPO Instrument CDR | Successful | FY 2018 Q2 |
| Perform-ance | SRB | Jun 2015 | GEDI System Requirement Review/Mission Design Review | Successful | Jan 2016 |
| Perform-ance | SRB | Jul 2015 | ECOSTRESS PDR | Successful | Oct 2015 |
| Perform-ance | SRB | Aug 2015 | CYGNSS KDP-D Milestone Review | Successful | Aug 2016 |
| Perform-ance | SRB | Oct 2015 | ECOSTRESS Instrument KDP-C Milestone Review to determine readiness to enter development | ECOSTRESS Instrument approved to enter development | Dec 2015 |
| Perform-ance | SRB | Dec 2015 | ECOSTRESS full project KDP-C confirmation review | Successful | FY 2016 Q2 |
| Perform-ance | SRB | FY 2016 Q2 | ECOSTRESS CDR | TBD | FY 2019 Q4 |

# VENTURE CLASS MISSIONS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | SRB | FY 2016 Q2 | GEDI KDP-C Milestone Review to determine readiness to enter development | TBD | FY 2017 Q1 |
| Perform-ance | SRB | Jan 2016 | GEDI PDR | TBD | FY 2016 Q2 |
| Perform-ance | SRB | Aug 2016 | CYGNSS ORR | TBD | N/A |
| Perform-ance | SRB | FY 2017 Q1 | GEDI CDR | TBD | FY 2019 Q2 |
| Perform-ance | SRB | FY 2018 Q2 | TEMPO KDP-C Milestone Review to establish hosting costs | TBD | FY 2021 Q3 |
| Perform-ance | SRB | FY 2019 Q2 | GEDI ORR | TBD | N/A |
| Perform-ance | SRB | FY 2019 Q4 | ECOSTRESS ORR | TBD | N/A |
| Perform-ance | SRB | FY 2021 Q3 | TEMPO ORR | TBD | N/A |

# OTHER MISSIONS AND DATA ANALYSIS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| ESSP Missions Research | 13.4 | -- | **13.2** | 15.9 | 17.0 | 19.7 | 21.0 |
| Orbiting Carbon Observatory-3 | 1.5 | -- | **26.3** | 9.5 | 4.2 | 6.6 | 6.8 |
| Small Satellite Constellation Initiative | 0.0 | -- | **30.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| OCO-2 | 17.5 | -- | **10.2** | 10.1 | 10.4 | 10.0 | 10.2 |
| Aquarius | 3.4 | -- | **3.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| GRACE | 5.0 | -- | **5.4** | 2.3 | 1.3 | 0.0 | 0.0 |
| Cloudsat | 7.5 | -- | **8.5** | 4.1 | 2.0 | 0.0 | 0.0 |
| Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) | 6.4 | -- | **5.1** | 7.1 | 7.1 | 7.2 | 7.3 |
| **Total Budget** | **54.6** | **--** | **101.7** | **49.0** | **42.0** | **43.5** | **45.2** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

ESSP Other Missions and Data Analysis projects include operating missions and mission-specific research. These innovative missions will enhance understanding of the current state of the Earth system and enable continual improvement in the prediction of future changes.

## Mission Planning and Other Projects

### ESSP MISSIONS RESEARCH

ESSP Missions Research provides funds for the science teams supporting ESSP operating missions. The science teams are comprised of competitively selected individual investigators who analyze data from the missions to address relevant science questions.

#### Recent Achievements

A study presented the first measurements of Lower North Atlantic Deep Water transport changes using only time-variable gravity observations from GRACE satellites from 2003 until now. The study demonstrated the efficacy of space observations of the Atlantic Meridional Overturning Circulation (AMOC) variations. The AMOC plays a key role in the poleward transport of heat. Changes in this transport can influence climate at higher latitudes significantly, with potentially significant impacts for the Northern Hemisphere, in particular northwest Europe’s climate.

A study demonstrated the impact of combined Aquarius and in-situ sea surface salinity measurements on El Nino forecasts, using a coupled ocean-atmosphere model for August 2011 until February 2014. Scientists used these observations to initialize coupled El Nino forecast experiments. Assimilating Aquarius SSS gave significant improvement over the baseline for all forecast lead times after five months.

# OTHER MISSIONS AND DATA ANALYSIS

A recent study describes a climatology of vertical distributions of cloud water content, ice water content, and cloud fraction associated with eight different cloud types, by utilizing the combined CloudSat radar and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) lidar measurements. The team also analyzed the geographical and seasonal variations of these cloud properties for each cloud type. Results show that different cloud types have different altitudes of cloud water content and cloud fraction peaks, and the altitude of the cloud fraction peak does not always overlap with that of cloud water content peak. This study provides an important baseline for comparing observations with global General Circulation Models.

## ORBITING CARBON OBSERVATORY (OCO)-3

The Orbiting Carbon Observatory (OCO)-3 is a space instrument that will investigate important questions about the distribution of carbon dioxide on Earth as it relates to growing urban populations and changing patterns of fossil fuel combustion. OCO-3 will explore, for the first time, daily variations in the release and uptake of carbon dioxide by plants and trees in the major tropical rainforests of South America, Africa, and South-East Asia, which are the largest stores of aboveground carbon on our planet. Measuring the daily variations in these major carbon systems addresses an important missing component in our knowledge, and is crucial for explaining global variations in atmospheric carbon dioxide levels. NASA will develop and assemble the instrument using spare materials from OCO-2 and host the instrument on the ISS.

### Recent Achievements

The project restarted in FY 2016 and now works towards a confirmation review.

## SMALL SATELLITE CONSTELLATIONS INITIATIVE

This is a new effort proposed for FY 2017 and supported by mandatory funding. Potential small satellite constellation activities include on-orbit technology validation and risk reduction for small instruments; fostering commercial launch services dedicated to transporting small payloads into orbit; funding competitive grants for small satellite proposals; and exploring governance models to incentivize Center involvement in small satellite constellation proposals.

# Operating Missions

## OCO-2

Since the beginning of the industrial age, the concentration of carbon dioxide in the Earth’s atmosphere increased more than 38 percent. Scientific studies indicate that carbon dioxide is one of several greenhouse gases that trap heat near the Earth’s surface. Most scientists have concluded that substantial increases in carbon dioxide in the atmosphere will increase the Earth’s surface temperature, referred to as global warming.

From its vantage point in low Earth orbit, OCO-2 collects hundreds of thousands of precise carbon dioxide measurements across the globe each day. With these data, scientists are gaining greater insight into how much of carbon dioxide the Earth emits by natural sources and human activities, and into the natural processes removing carbon dioxide from the atmosphere. This information may help decision-makers to manage carbon dioxide emissions and reduce the human impact on the environment.

### Recent Achievements

OCO-2 officially entered its prime operations phase in October 2014 and has routinely delivered science data products for distribution to the science community since the second quarter of FY 2015. These products include calibrated spectra of reflected sunlight as well as the carbon dioxide and solar-induced chlorophyll florescence estimates derived from these spectra. Measurements collected during its first year of operations clearly reveal well-known features of the carbon dioxide distribution, including the strong spring “drawdown” that occurs in the northern hemisphere spring, as plants on land pull carbon dioxide from the air to produce new leaves, stems, and roots. Emissions associated with intense fossil fuel combustion and biomass burning are clearly shown by the satellite data.

## GRAVITY RECOVERY AND CLIMATE EXPERIMENT (GRACE)

Gravity Recovery and Climate Experiment (GRACE) measures minute changes in Earth’s gravity field by measuring micron-scale variations in the separation between the two spacecraft that fly in formation 220 kilometers apart in low Earth orbit. Local changes in Earth’s mass cause the variations in gravitational pull. GRACE demonstrated a new paradigm of observations that utilizes ultra-small variations of Earth’s gravity field, as small as one-billionth the surface force of gravity. With this capability, GRACE was the first mission to provide a comprehensive measurement of the monthly change in the ice sheets and major glaciers. GRACE provided significant new information on changes in water resources within river basins and aquifers worldwide, and measured the effects of major earthquakes around the world. NASA developed the twin GRACE satellites in collaboration with German Aerospace Center (DLR).

Launched in 2002, the mission lifetime now exceeds 13 years. The 2015 Earth Science senior review endorsed the GRACE mission for continued operations through 2017 and preliminarily through 2019, or until re-entry, currently projected to occur in 2018. The next senior review will occur in 2017, and will re-evaluate the GRACE mission extension in terms of scientific value, national interest, technical performance, orbit status, and proposed cost in relation to NASA Earth Science strategic plans.

### Recent Achievements

The GRACE data set significantly improved the capability for measuring seasonal and decadal mass variations associated with: terrestrial water storage, continental aquifers, deep ocean currents, water storage in the major river basins, polar ice mass, and the mass redistribution signals associated with large earthquakes and post-glacial rebound. Research using GRACE data has shown that a third of the world’s biggest groundwater basins are in distress. Near real-time data products from GRACE, support applications to analyze flooding, drought, and earthquake events.

## CLOUDSAT

CloudSat measures cloud characteristics to increase understanding of the role of clouds in Earth’s radiation budget. This mission specifically provides estimates of the percentage of Earth’s clouds that produce rain, provides vertically-resolved estimates of how much water and ice are in Earth’s clouds, and estimates how efficiently the atmosphere produces rain from condensates. CloudSat collects information about the vertical structure of clouds and aerosols that other Earth-observing satellites do not collect. This data improves models and provides a better understanding of the human impact on the atmosphere. CloudSat launched in 2006, and is currently in extended operations.

The 2015 Earth Science senior review endorsed the CloudSat mission for continued operations through 2017 and preliminarily through 2019. The next senior review will occur in 2017, and will re-evaluate the CloudSat mission extension in terms of scientific value, national interest, technical performance, and proposed cost in relation to NASA Earth Science strategic plans.

### Recent Achievements

CloudSat continues to provide unique, vertically resolved global observations of clouds and precipitation that lead to a clearer understanding of how clouds influence Earth's climate. The observations are widely used in model evaluation and in development of new moist physical processes in weather and climate prediction models. With last year's entry of the OCO-2 mission into the A-Train constellation (a satellite constellation of six Earth observation satellites of varied nationality in sun-synchronous orbit at an altitude of 705 kilometers above the Earth), CloudSat began development of new cloud products that use data from both missions. The effort focuses initially on low, stratiform clouds (low-level, stable, non-precipitating cloud layer), builds upon existing A-Train related cloud products, and exploits A-Train observations to help constrain the retrievals and to test product information. The project performs development of the product with close coordination with the OCO-2 algorithm team.

## CLOUD-AEROSOL LIDAR AND INFRARED PATHFINDER SATELLITE OBSERVATION (CALIPSO)

CALIPSO provides data on the vertical structure of clouds, the geographic and vertical distribution of aerosols, and detects sub-visible clouds in the upper troposphere. CALIPSO also provides an indirect estimate of the contribution of clouds and aerosols to atmospheric warming. Since its launch in 2006, CALIPSO has been part of the A-Train constellation (with CloudSat, Aura, Aqua, CNES's Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar [PARASOL], JAXA's Global Change Observation Mission 1st - Water [GCOM-W1], and now OCO-2). It is in extended operations.

Atmospheric aerosols can affect Earth's radiation balance, the formation of clouds and precipitation, the chemical composition of the atmosphere, and pose a health risk when pollution levels rise. CALIPSO provides the first comprehensive three-dimensional measurement record of aerosols, helping to better understand how aerosols form, evolve, and are transported over the globe. The 2015 Earth Science senior review endorsed the CALIPSO mission for continued operations through 2017 and preliminarily through 2019. The next senior review will occur in 2017, and will re-evaluate the CALIPSO mission extension in terms of scientific value, national interest, technical performance, and proposed cost in relation to NASA Earth Science strategic plans.

### Recent Achievements

CALIPSO measurements helped advance our understanding of the geographical and vertical distribution of clouds over the globe and of how much water and ice they hold. The use of active sensor on CALIPSO improved the understanding of cloud effects in the Polar Regions, showing that radiative forcing of wintertime clouds can influence summer time sea ice loss in the Arctic, and improving models of poleward energy transport from the Southern Ocean. Combining five years of A-Train data from

# OTHER MISSIONS AND DATA ANALYSIS

CALIPSO, CloudSat, and Aqua enabled researchers to quantify the effects of aerosols and clouds, improving weather and climate models.

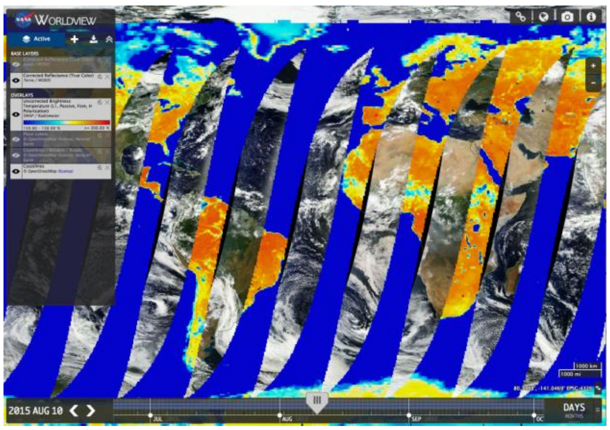
# EARTH SCIENCE MULTI-MISSION OPERATIONS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **179.7** | **--** | **191.8** | **194.3** | **193.6** | **197.9** | **202.6** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*




**Full resolution imagery from the NASA SMAP Mission is now available through the Global Image Browse System and is visible in Worldview. New additions include the SMAP Level 1 global radiometer products.**

The Earth Science Multi-Mission Operations (MMO) program acquires, processes, preserves, and distributes observational data from operating spacecraft to support Earth Science research focus areas. The MMO program primarily accomplishes this via the Earth Observing System Data and Information System (EOSDIS), which has been in operations since 1994. The EOSDIS team creates earth science data products from satellite data that arrives at the rate of more than four terabytes per day.

The archiving of NASA Earth Science information happens at Distributed Active Archive Centers (DAACs) located across the United States. The DAACs specialize by science discipline, and make their data available to researchers around the world.

The MMO program supports the science data segment for Suomi NPP, as well as the data archive and distribution for the recently launched SMAP, GPM, and OCO-2 missions and upcoming Earth Science missions. EOSDIS data centers also support Earth Ventures Suborbital campaigns. A system plan for 2016 and beyond will take into account evolutionary needs for new missions in development, in response to the National Academies decadal survey. These investments will enable the system to keep technologically current, and incorporate new research data and services.

For more information, go to http://science.nasa.gov/earth-science/earth-science-data.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

The MMO budget supports upcoming requirements for ICESat-2, TEMPO, OCO-3, SAGE-III, and TSIS-1 on ISS, which will provide a range of data sets over the budget horizon for land, ocean, and atmospheric monitoring. In addition, the MMO budget increase will support new efforts associated with citizen science and developing improved capabilities for the discovery and usage of global change information.

# EARTH SCIENCE MULTI-MISSION OPERATIONS

## ACHIEVEMENTS IN FY 2015

EOSDIS expanded its capabilities to accommodate data from SMAP, OCO-2, AMSR2, GPM, RapidScat, and airborne missions, including IceBridge and EV-1. The five EOSDIS Science Investigator-led Processing Systems (SIPS) initiated production of NASA science data products from Suomi NPP in FY 2015.

New technologies were developed and implemented to make earth science data more broadly available. EOSDIS began consolidation of multiple metadata systems into a single Common Metadata Repository that supports sub second search of over 250 million records. Common Application Programing Interfaces, such as Open Source Project for a Network Data Access Protocol (OPeNDAP), were deployed increasing efficient access to petabytes of data from EOSDIS. The Global Imagery Browse Services added 51 new imagery products from five instruments allowing comparison of data from multiple instruments. In addition to these new products, the project generated ongoing imagery for 93 imagery products. The team performed these activities as part of the Big Earth Data Initiative.

The European Commission and ESA reached agreement to acquire, archive, and distribute data from the Copernicus Program's Sentinel Missions. NASA established a Sentinel Gateway and began acquiring strategic aperture radar data from the Sentinel 1-A mission, which will be freely and readily available to the science community and other users.

Principal Investigators from the 2013 Advancing Collaborative Connections for Earth System Science (ACCESS) selection entered their second year of funding, with annual reports submitted in preparation for reviews of their first year's activities.

As the technical lead for the implementation of the White House Climate Data Initiative, NASA worked with other Federal agencies to identify and catalog federally held data and information. The project has made over one thousand curated data sets from multiple federal agencies available in the following thematic areas: coastal flooding, food resilience, water resources, ecosystems, human health, energy infrastructure and transportation systems, as well as natural, economic, and cultural resources in the Arctic. For more information, go to http://climate.data.gov.

## WORK IN PROGRESS IN FY 2016

Standard production of Suomi NPP data sets will ramp up to provide continuity with Earth Science Data Records from the EOS missions. Data products from Suomi NPP will be available to the science and application communities as standard products available within days of observation and near-real time products available within three hours of observation. The project will acquire and archive data from the Copernicus Program's Sentinel-3 mission at DAACs with related data sets. The EOSDIS will continue to provide leadership and participation in inter-agency and international efforts on science data interoperability, access, standards, and stewardship. EOSDIS will chair the Committee on Earth Observing Satellites Working Group on Information Systems and Services, will co-chair the U.S. Group on Earth Observations Data Management Working Group, and will support the Administration's Big Earth Data Initiative and Climate Data Initiative. EOSDIS will begin releasing data from several new missions. Finally, the EOSDIS will embark on several prototypes to evaluate the technical feasibility and cost effectiveness of cloud computing technology.

# EARTH SCIENCE MULTI-MISSION OPERATIONS

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA will continue to operate and maintain the EOSDIS, and all accompanying infrastructure and functions. NASA also anticipates providing data systems support for several new missions aboard the ISS (e.g., TEMPO, LIS, SAGE-III, TSIS) and airborne mission from EVS-2 as well as preparations for the ICESat-2 and GRACE-FO missions. Scientists will use results of cloud prototyping to evolve the data system. The team will deploy new services to improve data utilization. NASA will release the 2017 ACCESS solicitation.

# Program Elements

## EARTH SCIENCE MULTI-MISSION OPERATIONS

This project funds the evolution of EOSDIS elements, aimed at improving the efficiency and effectiveness of EOSDIS while reducing the cost. It also supports the twelve nationwide DAAC installations that collect, disseminate, and archive earth science data. Each DAAC focuses on a specific Earth system science discipline and provides users with data products, services, and data-handling tools unique to that specialty.

- The Alaska Synthetic Aperture Radar Facility, which collects data and information on sea ice, polar processes, and geophysics;
- The GSFC Earth Sciences Data and Information Services Center, which collects information on atmospheric composition, atmospheric dynamics, global precipitation, ocean biology, ocean dynamics, and solar irradiance;
- The LaRC DAAC collects data on Earth’s radiation budget, clouds, aerosols, and tropospheric chemistry;
- The Land Processes DAAC collects land processes data;
- The National Snow and Ice Data Center collects snow and ice data, as well as information about the cryosphere and climate;
- The Oak Ridge National Laboratory DAAC collects data on biogeochemical dynamics and ecological data for studying environmental processes;
- The Physical Oceanography DAAC collects information on oceanic processes and air-sea interactions;
- The Socioeconomic Data and Applications Center collects information on population, sustainability, multilateral environmental agreements, natural hazards, and poverty;
- The Crustal Dynamics Data Center collects information focused on solid earth data;
- The Ocean Biology Progressing Group produces and distributes ocean biology and biogeochemistry products;
- The Global Hydrology Research Center provides hydrological cycle and severe weather research data and information; and
- The Land and Atmosphere Data Center provides a large suite of MODIS atmospheric products.

# EARTH SCIENCE MULTI-MISSION OPERATIONS

## EARTH OBSERVING SYSTEM DATA AND INFORMATION SYSTEM (EOSDIS)

The EOSDIS project provides science data to a wide community of users, including NASA, Federal agencies, international partners, academia, and the public. EOSDIS provides users with the services and tools they need in order to use NASA's earth science data in research and creation of models. EOSDIS archives and distributes data through standardized science data products, using algorithms and software developed by Earth Science investigators.

The EOSDIS project also funds research opportunities related to EOSDIS. Current programs include ACCESS and Making Earth System data records for Use in Research Environments (MEaSUREs).

ACCESS projects increase the interconnectedness and reuse of key information-technology software and services in use across the spectrum of earth science investigations. ACCESS also supports the deployment of data and information systems and services that enable the freer movement of data and information. ACCESS researchers develop needed tools and services to aid in measurable improvements to earth science data access and usability.

Through the MEaSUREs activity, researchers investigate new types of sensors to provide three-dimensional profiles of Earth's atmosphere and surface. There is an emphasis on linking data from multiple satellites, and then facilitating the use of this data in the development of comprehensive Earth system models.

## Program Schedule

MMO solicits research opportunities every two years for ACCESS and every five years for MEaSUREs.

| Date | Significant Event |
|---|---|
| Q2 FY 2017 | ROSES MEaSUREs Solicitation Released |
| Q2 FY 2017 | ROSES ACCESS Solicitation Released |

## Program Management & Commitments

| Program Element | Provider |
|---|---|
| EOSDIS core system, and Evolution of EOSDIS upgrades | Provider: GSFC<br>Lead Center: GSFC<br>Performing Center(s): GSFC<br>Cost Share Partner(s): N/A |

# EARTH SCIENCE MULTI-MISSION OPERATIONS

| Program Element | Provider |
|---|---|
| DAACs | Provider: Various<br>Lead Center: GSFC<br>Performing Center(s): GSFC, LaRC, Marshall Space Flight Center (MSFC), JPL<br>Cost Share Partner(s): N/A |

## Acquisition Strategy

Research opportunities related to EOSDIS are available through NASA's ROSES announcements.

### MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
|---|---|---|
| EOSDIS Evolution & Development | Raytheon | Riverdale, MD |

### INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Quality | American Customer Satisfaction Index | 2015 | Survey current EOSDIS users to assess current status and improve future services | EOSDIS scored 89 out of 100, a strong score and above the Federal government average. EOSDIS improved in several areas including "likelihood to recommend" and "likelihood to use services in the future." | 2016 annually thereafter |

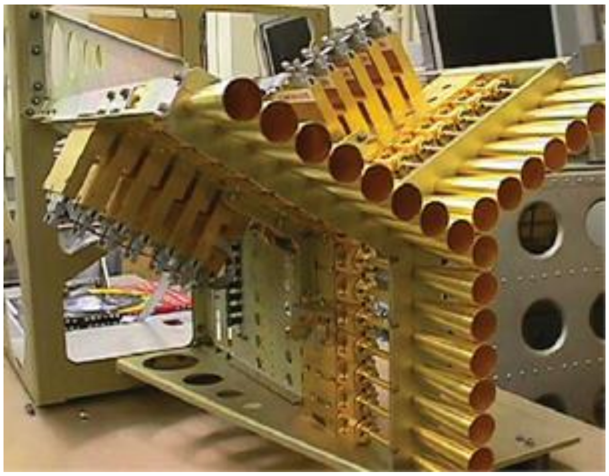
# EARTH SCIENCE TECHNOLOGY

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Total Budget | 59.7 | -- | 61.4 | 60.4 | 59.7 | 62.7 | 63.7 |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**Developed at JPL, this prototype of a geostationary microwave sounder, the Geostationary Thinned Aperture Radiometer (GeoSTAR) is part of the Instrument Incubator Program (IIP). It completed a first-light demonstration in September 2015. Using a geostationary orbit, this atmospheric research and weather forecasting instrument will improve upon existing measurements by providing continuous coverage in all weather conditions, have rapid data refresh rates for monitoring severe weather, and improve hurricane tracking capability.**

Advanced technology plays a major role in enabling Earth research and applications. The Earth Science Technology Program (ESTP) enables previously infeasible science investigations; improves existing measurement capabilities; and reduces the cost, risk, and/or development times for earth science instruments and information systems.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## ACHIEVEMENTS IN FY 2015

Principal investigators made satisfactory progress on all awards in the IIP, Advanced Information Systems Technology, and Advanced Components Technology programs. NASA launched the GEO-CAPE Read-Out Integrated Circuit (ROIC) In-Flight Performance Experiment (GRIFEX) CubeSat with the SMAP mission in January 2015 and successfully completed its technology validation activities including engineering assessments of a digital in-pixel high frame rate ROIC.

NASA selected four new selections for the In-Space Validation of Earth Science Technology (InVEST)-15. The space environment imposes stringent conditions on components and systems, some of which are not possible to test on the ground or in airborne systems. Because of the harsh conditions, there has been, and continues to be, a need for new technologies to be validated in space prior to use in a science mission. The InVEST program element will fill that gap. NASA targeted the InVEST call to small instruments and instrument subsystems that can advance technology to enable relevant earth science measurements. The call was limited to in-space validation only, and targeted to the CubeSat platform.

# EARTH SCIENCE TECHNOLOGY

During FY 2015, 40 percent of active technology projects advanced at least one technology readiness level, and several projects factored into science measurements, system demonstrations, or other applications.

### WORK IN PROGRESS IN FY 2016

In FY 2016, ESTP will develop new remote sensing and information systems technologies for infusion into future science missions and airborne campaigns. These technologies will enable or enhance measurements and data systems capabilities. Instrument, component, and information systems technology activities awarded in prior solicitations will advance toward incorporation into decadal survey and Venture-class missions, and NASA Earth Science deployments. The five in-space technology flight validation awards made in FY 2013 will be in their last year of development and will be targeting launches in the FY 2016 to early FY 2017 period. ESTP will initiate work in the four new InVEST tasks made in FY 2015. The 11 most recent Advanced Components Technology awards are underway this year and will complete first year activities. The Advanced Information Systems Technology program made 24 awards in FY 2015 and all of these awards are underway in their first year of activities. Work continues on advancing technology developments in all of the 17 awards made in the IIP-13 solicitation.

### KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA anticipates making new awards in Q2 FY 2017 from the Instrument Incubator Program and Advanced Information Systems Technology program from the ROSES FY 2016 solicitation.

## Program Elements

### ADVANCED TECHNOLOGY INITIATIVES (ATI)

This project enables development of critical component and subsystem technologies for instruments and platforms, mostly in support of the Earth Science decadal survey. Current awards focus on areas such as space-qualified laser transmitters, passive optical technologies, and microwave and calibration technologies. Other awards support measurements of solar radiance, ozone, aerosols, and atmospheric gas columns for air quality and ocean color for coastal ecosystem health and climate emissions.

The InVEST program element selects new technologies to validate in space prior to use in a science mission. This is necessary because the space environment imposes stringent conditions on components and systems, some of which we cannot test on the ground or in airborne systems. Validation of earth science technologies in space will help reduce the risk of new technologies in future Earth Science missions.

### INSTRUMENT INCUBATOR

This project develops instrument and measurement techniques at the system level, including laboratory breadboards and operational prototypes for airborne validation. NASA currently funds 17 Instrument Incubator efforts. These instrument prototypes support several measurements such as carbon dioxide, carbon monoxide, ocean color, and solar spectrum from ultraviolet to infrared for climate science.

# EARTH SCIENCE TECHNOLOGY

Instrument Incubator supports the development of instrument design, prototype through laboratory and/or airborne demonstrations for innovative measurement techniques that have the highest potential to meet the measurement capability requirements of the NASA earth science community in both the optical and the microwave spectrum.

## ADVANCED INFORMATION SYSTEMS TECHNOLOGY (AIST)

This project develops end-to-end information technologies that enable new Earth observation measurements and information products. The technologies help process, archive, and access, visualize, communicate, and understand science data. Currently, Advanced Information Systems Technology (AIST) activities focus on four areas needed to support future earth science measurements:

- Concept Development of Improved Sensor Measurements, which includes tools to help assess various types of measurements and how to make them, including technologies that aid in the design and analysis of quantitative observations;
- Data Acquisition and Management, which refers to the collection and management of high-volume and/or high-rate data and supports the building and operation of infrastructures that are necessary for sensor data acquisition;
- Data Product Generation, which is the creation of interdisciplinary products that aggregate observational data, thus improving the scientific value of the data at reduced costs; and
- Exploitation of Data for Earth Science and Applications, which focuses on the transformation of data products into actionable information and includes modeling and visualization tools, as well as collaborative environments. In general, projects aim to advance the discovery, access, and use of sensor data within the Earth Science community.

## Program Schedule

| Date | Significant Event |
|---:|---|
| Q2 FY 2016 | ROSES-2016 solicitation |
| Q1 FY 2017 | ROSES-2016 selection no earlier than 6 months of receipt of proposals |
| Q2 FY 2017 | ROSES-2017 solicitation |
| Q1 FY 2018 | ROSES-2017 selection no earlier than 6 months of receipt of proposals |
| Q2 FY 2018 | ROSES-2018 solicitation |
| Q1 FY 2019 | ROSES-2018 selection no earlier than 6 months of receipt of proposals |
| Q2 FY 2019 | ROSES-2019 solicitation |
| Q1 FY 2020 | ROSES-2019 selection no earlier than 6 months of receipt of proposals |
| Q2 FY 2020 | ROSES-2020 solicitation |

# Program Management & Commitments

| Program Element | Provider |
|---|---|
| Instrument Incubator | Provider: Various<br>Lead Center: HQ<br>Performing Center(s): GSFC, JPL, LaRC, ARC, AFRC<br>Cost Share Partner(s): N/A |
| Advanced Information Systems | Provider: Various<br>Lead Center: HQ<br>Performing Center(s): GSFC, JPL, LaRC, MSFC, ARC, GRC<br>Cost Share Partner(s): N/A |
| Advanced Technology Initiatives | Provider: Various<br>Lead Center: HQ<br>Performing Center(s): GSFC, JPL, LaRC<br>Cost Share Partner(s): N/A |

# Acquisition Strategy

NASA primarily procures tasks through full and open competition, such as through the ROSES announcements. The solicitation of technology investments is competitive and selected from NASA Centers, industry, and academia.

## MAJOR CONTRACTS/AWARDS

None.

# EARTH SCIENCE TECHNOLOGY

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | NASA Advisory Council Earth Science Subcommittee | 2012 | Review for success in infusion of new technologies and participation of universities in developing the new generation of technologists. | The committee was pleased with the technology program; it recommended focusing on reducing cost in missions and enabling specific measurements. Reports are available at https://esto.nasa.gov. | 2016, 2018 |

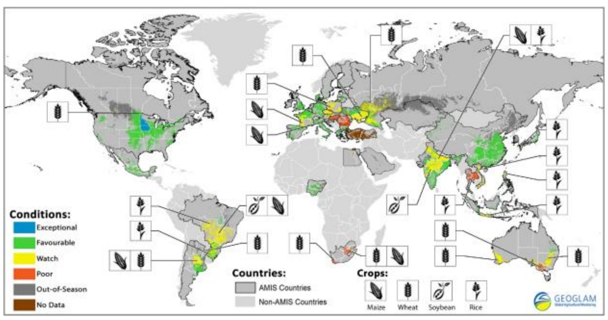
# APPLIED SCIENCES

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **40.4** | **--** | **48.2** | **47.9** | **48.7** | **51.5** | **52.0** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*




The Global Agricultural Monitoring initiative (GEOGLAM) strengthens the international community's capacity to produce and disseminate timely forecasts of agricultural production at multiple scales through the use of Earth observations. On a monthly basis, the GEOGLAM Crop Monitor provides transparent, in-season assessments of crop growing conditions and outputs, which helps stabilize markets and reduce price volatility. This image for November 2015 shows the crop conditions over the main growing areas for wheat, maize, rice, and soybeans.

The NASA Applied Sciences program leverages NASA Earth Science satellite measurements and new scientific knowledge to provide innovative and practical uses for public and private sector organizations. It also enables near-term uses of earth science knowledge, discovers and demonstrates new applications, and facilitates adoption of applications by public and private sector stakeholder organizations.

Applied Sciences projects improve decision-making activities to help the Nation better manage its resources, improve quality of life, and strengthen the economy. NASA develops earth science applications in collaboration with end-users in public, private, and academic organizations.

Examples of these applications include:

- Development of drought indicators with the National Drought Mitigation Center to support end users' conservation and agriculture decisions;
- Application of land cover information by the Nature Conservancy to conduct a reverse auction, pay landowners, and increase prime habitat for migrating wild birds;
- Use of higher-resolution wildfire detection data by the U.S. Forest Service to improve determination of fire boundaries and expedite restoration of key ecosystems;
- Advances in fishery stock assessments with NOAA's National Marine Fisheries Service for sustainable management of important commercial species;
- Support early warnings and risk maps of infectious diseases to help health officials anticipate outbreaks and take timely actions for disease control and prevention;
- Use of satellite observations of volcanic ash to inform air traffic controllers and aviation industry for hazards along major airplane routes; and
- Improved forecasts of crop water needs in California's Central Valley to account for optimal irrigation rates when scheduling irrigation.

The program supports the sustained use of these products in the decision-making process of user organizations. The program also encourages potential users to envision and anticipate possible applications from upcoming satellite missions and to provide input to mission development teams to increase the societal benefits of NASA missions.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

The FY 2017 budget restores funding for a follow-on Applied Sciences Team for the SERVIR project, to improve regional hubs and national stakeholders and users' abilities to apply Earth observations. This second three-year SERVIR Applied Sciences Team will provide geographic and thematic applied science expertise and applications projects to four hubs, focusing on food security, land use and ecosystems, climate, and water and water-related disasters. NASA manages SERVIR jointly with the United States Agency for International Development.

The FY 2017 budget allows for NASA's scientific support to an expanded SERVIR global network encompassing six regional hubs planned after 2017. The budget allows an expanded third SERVIR Applied Sciences Team to provide scientific expertise and applications projects across the six hubs.

The FY 2017 budget completes and closes-out the crosscutting Wildfires applications theme for Applied Sciences.

## ACHIEVEMENTS IN FY 2015

The California Department of Water Resources and other state and Federal agencies applied Landsat, Terra, and Aqua satellite observations to create monthly fallowed-area maps of the Central Valley, allowing them to gauge idle agricultural land and support state allocation of drought emergency funds. The Nature Conservancy applied NASA MODIS and ASTER land cover data to identify wetlands as part of a reverse auction with landowners to increase habitat along the Pacific flyway for migrating wild birds.

NASA used the vantage point of space to support the response to numerous national and international disasters. For example, NASA supported the response to flooding in Texas and surrounding areas, including information from GPM satellite and flood models to characterize extent of the event and to aid decisions on closures of navigational rivers in Oklahoma and Arkansas. NASA supported the international response to the Gorkha earthquake in Nepal, providing information products on damage proxy maps, landslides, deformation models, and vulnerability maps derived from satellite data.

NASA continued its phased approach to conduct applications projects – initially supporting a set of feasibility studies and then selecting a subset to pursue as in-depth projects. In 2015, the ecological forecasting applications area selected ten feasibility studies to continue as in-depth applications projects.

The Water Resources applications area initiated nine projects addressing seasonal outlooks of water supply conditions. The Health & Air Quality applications area began nine new projects addressing applications of Earth observations environmental health risks and infectious diseases, such as cholera, west Nile virus, and heat stress.

The DEVELOP program, an endeavor for young professionals to apply earth science data, included over 400 people in 91 projects. Applied Sciences' training endeavor on remote sensing for professionals conducted a dozen virtual and in-person training programs, reaching over two thousand people for the first time across the United States and globally. The SERVIR program (managed jointly with the U.S. Agency for International Development) officially launched its new regional hub in Southeast Asia to enhance decision-making using satellite observations in the Lower Mekong River basin.

Applied Sciences engaged the applications community to expand knowledge about NASA's Earth Science missions and in planning for upcoming satellites. The NISAR, SWOT, and CYGNSS missions held their first applications workshops, PACE held an applications town hall forum, GPM held its first applications workshop since launch, the GRACE mission delivered an applications plan, and the SMAP and ICESat-2 missions expanded their numbers of early adopters to apply the data and information.

## WORK IN PROGRESS IN FY 2016

NASA will begin implementing a new strategic plan for the Applied Sciences Program that covers the 2016-2020 timeframe. As part of this, NASA will commence initiatives on freshwater availability with the Western states and food security, supporting the nation's use of Earth observations to address these challenges. The year will be the first full year under NASA's new preparatory-based approach to disaster response, working with more disaster groups that can carry forward NASA-developed information and tools to support the responders they serve.

Projects from the first NASA Air Quality Applied Sciences Team will complete, providing new tools to air quality managers to improve forecasting and planning decisions. NASA will solicit and select members of a follow-on team, which will focus more on engaging state air quality and public managers to identify and conduct targeted, near-term projects. The water resources area will deliver results in projects focused on use of Earth observations to improve drought forecasts and land management practices, and the ecological forecasting area will deliver results from projects addressing climate effects in ecosystem management strategies.

The first SERVIR Applied Sciences Team will complete their core projects, delivering results on uses of Earth observations to advance water management, agriculture, health, and disaster preparedness in Africa, Himalayas, and Central America. Results from the new SERVIR-Mekong hub will begin, and NASA and United States Agency for International Development (USAID) will likely identify a new hub in West Africa to increase use of Earth observations and geospatial information in that region. The Applied Remote Sensing Training (ARSET) project will conduct its first wildfires training course and pursue one on public health as part of its plans to broaden and reach users.

Applied Sciences will continue its engagement with the applications community as part of current and future NASA earth science missions, such as an applications workshop for the NISAR mission and expansion of Early Adopter programs to more missions. The program will sponsor a symposium on the socioeconomic benefits of Earth observations, and it will solicit and select projects to advance impact assessment methodologies.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

The program will deliver results in projects focused on use of Earth observations in wildfires management activities, including projects that address the pre-, active, and post-fire phases. The program will deliver results from disaster management applications on topics involving flooding, storm damage assessments, and volcanic ash alerts. The water resources area and disasters area will select and start new portfolios of projects.

The SERVIR project will initiate its second applied sciences team to improve regional hubs and national stakeholders and users' abilities to apply Earth observations. This team will provide geographic and thematic applied science expertise and applications projects to four hubs, focusing on food security, land use and ecosystems, climate, and water and water-related disasters.

## Program Elements

### CAPACITY BUILDING

The Capacity Building project enhances U.S. and developing countries' capacity, including human, scientific, technological, institutional, and resource capabilities, to make decisions informed by earth science data and models. Capacity Building builds skills in current and future workforce, and it creates opportunities in under-served areas to broaden the benefits of Earth observations. This project supports training, information product development, internships, data access tools, short-term application test projects, user engagement, and partnership development. This project has three primary elements: SERVIR for supporting developing countries, ARSET for professional-level training on Earth observations, and DEVELOP for workshop development through hands-on internships with state and local governments.

### MISSION AND APPLIED RESEARCH

The Mission and Applied Research project enables involvement by applications-oriented users in the planning, development, and other activities of Earth Science satellite missions. The Mission and Applied Research project enables end user engagement to identify applications early and throughout mission life cycle, integrate end-user needs in design and development, enable user feedback, and broaden advocacy. Mission and Applied Research organizes community workshops to identify priority needs as well as studies to inform design trade-offs and identify ways to increase the applications value of missions. In this project, Applied Sciences advises flight projects on activities to develop the applications dimension of the mission to help broaden benefits and maximize the return from the investment in the mission.

### DISASTER SUPPORT

The Disaster Support project enables development of innovative applications using NASA satellite mission data to ensure timely, valuable support to responders when disasters occur. The Disaster Support project sponsors the use and integration of Earth observations in disaster-related organizations' decisions and actions, including use of feasibility studies, in-depth projects, workshops, and needs assessments. The project also sponsors activities to improve a preparatory-based approach to enhance value and usability of NASA Earth Science products in support of disaster response and recovery. This project pursues partnerships with disaster groups that can carry forward NASA-developed information and tools to support the responders they serve.

# APPLIED SCIENCES

## APPLICATIONS

The Applications project organizes its development activities on priority themes related to societal and economic topics important to end user communities and their management, policy, and business activities. The Applications project sponsors the integration of Earth observations in community organizations' decisions and actions. Specific topics within an area evolve to reflect new priorities and opportunities. There are four formal applications areas in Ecosystems, Health, and Water and Wildfires. The project will conduct ad hoc activities on other themes and formalize areas when warranted or additional resources are available. Each applications area supports feasibility studies, in-depth projects, applied science teams, consortia, workshops, and needs assessments. Each applications area participates in major conferences and events that their partners attend in order to meet and engage managers and users.

## Program Schedule

| Date | Significant Event |
|---|---|
| 2016 Q1 | ROSES-2015 solicitation |
| FY 2016 Q2 | ROSES-2016 selection no earlier than 6 months of receipt of proposals |
| FY 2017 Q2 | ROSES-2017 selection no earlier than 6 months of receipt of proposals |
| FY 2018 Q2 | ROSES-2018 selection no earlier than 6 months of receipt of proposals |
| FY 2019 Q2 | ROSES-2019 selection no earlier than 6 months of receipt of proposals |
| FY 2020 Q2 | ROSES-2020 selection no earlier than 6 months of receipt of proposals |
| FY 2021 Q2 | ROSES-2021 selection no earlier than 6 months of receipt of proposals |

## Program Management & Commitments

| Program Element | Provider |
|---|---|
| Applications | Provider: Various<br>Lead Center: HQ<br>Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC<br>Cost Share Partner(s): U.S. Forest Service, National Park Service, U.S. Fish and Wildlife Service, Environmental Protection Agency (EPA), U.S. Department of Agriculture, NOAA, USGS, Bureau of Land Management, Centers for Disease Control and Prevention. |
| Capacity Building | Provider: Various<br>Lead Center: HQ<br>Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC, Stennis Space Center (SSC)<br>Cost Share Partner(s): USAID |

# APPLIED SCIENCES

| Program Element | Provider |
|---|---|
| Disaster Support | Provider: Various<br>Lead Center: HQ<br>Performing Center(s): GSFC, JPL, LaRC, MSFC, SSC<br>Cost Share Partner(s): Department of Homeland Security (DHS), NOAA, USDA, USGS, USAID |
| Mission and Applied Research | Provider: Various<br>Lead Center: HQ<br>Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC, SSC<br>Cost Share Partner(s): USDA, CNES, ISRO, Joint Research Centre (JRC) |

## Acquisition Strategy

NASA bases the Earth Science Applied Science acquisitions on full and open competition. Grants are peer reviewed and selected based on NASA research announcements and other related announcements.

### INDEPENDENT REVIEWS

None.

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Relevance | Applied Sciences Analysis Committee | Dec 2014 and Mar 2015 | Review strategy and implementation. Annual reports to NASA SMD/Earth Science Division Director. | Meeting report released Jun 2015 | Feb 2016; semi-annual thereafter |

# PLANETARY SCIENCE

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Planetary Science Research | 252.8 | -- | **284.7** | 271.6 | 285.7 | 281.6 | 287.3 |
| Discovery | 259.7 | -- | **202.5** | 277.3 | 337.4 | 345.0 | 405.3 |
| New Frontiers | 286.0 | -- | **144.0** | 81.6 | 90.7 | 142.8 | 234.0 |
| Mars Exploration | 305.0 | -- | **584.8** | 588.8 | 565.0 | 498.4 | 279.9 |
| Outer Planets and Ocean Worlds | 184.0 | -- | **137.3** | 56.0 | 77.8 | 128.0 | 247.3 |
| Technology | 159.2 | -- | **165.5** | 164.4 | 163.5 | 179.7 | 172.0 |
| **Total Budget** | **1446.7** | **--** | **1518.7** | **1439.7** | **1520.1** | **1575.5** | **1625.7** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

## Planetary Science

# PLANETARY SCIENCE RESEARCH

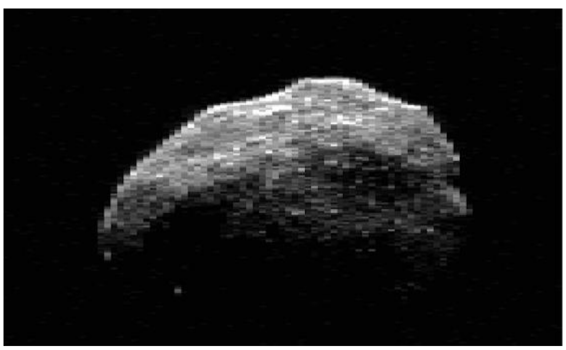
## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Planetary Science Research and Analysis | 162.4 | -- | **178.1** | 164.3 | 168.5 | 168.0 | 172.4 |
| Directorate Management | 4.0 | -- | **4.1** | 4.1 | 4.1 | 4.1 | 4.1 |
| Near Earth Object Observations | 40.0 | -- | **50.0** | 50.0 | 50.0 | 50.0 | 50.0 |
| Other Missions and Data Analysis | 46.4 | -- | **52.5** | 53.2 | 63.2 | 59.5 | 60.8 |
| **Total Budget** | **252.8** | **--** | **284.7** | **271.6** | **285.7** | **281.6** | **287.3** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*



**This high-resolution radar image of asteroid 2015 TB145 on a safe flyby of Earth on October 31, 2015, at about 1.3 lunar distances (300,000 miles, or 480,000 kilometers) was obtained by NASA scientists using the 230-foot (70-meter) Deep Space Network antenna at Goldstone, California, to transmit high-power microwaves toward the asteroid, from which the signal bounced back to Earth and its radar echoes were received by the National Radio Astronomy Observatory's 100-meter (330-foot) Green Bank Telescope in West Virginia.**

The Planetary Science Research program provides the scientific foundation for data sets returned from NASA missions exploring the solar system. It is also NASA's primary interface with university faculty and graduate students in this field and the research community in general. The program develops analytical and theoretical tools, as well as laboratory data, to support analysis of flight mission data. These capabilities allow Planetary Science to answer specific questions about, and increase the understanding of, the origin and evolution of the solar system. The research program achieves this by supporting research grants solicited annually and subjected to a competitive peer review before selection and award. The Planetary Science Research program focuses on five key research goals:

- Explore and observe the objects in the solar system to understand how they formed and evolved;
- Advance the understanding of how the chemical and physical processes in our solar system operate, interact, and evolve;
- Explore and find locations where life could have existed or could exist today;
- Improve our understanding of the origin and evolution of life on Earth to guide our search for life elsewhere; and
- Identify and characterize objects in the solar system that pose threats to Earth or offer resources for human exploration.

# PLANETARY SCIENCE RESEARCH

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Mandatory Budget Authority | -- | -- | 16.0 | -- | -- | -- | -- |

Planetary Science Research is supported in part with mandatory funding (see table, above). The mandatory investment includes $16 million for Planetary Research and Analysis to enhance the scientific return from on-going and completed spaceflight missions.

## ACHIEVEMENTS IN FY 2015

NASA's Astrobiology Program produced a number of exciting results in FY 2015:

A study showed that glycerol might form when ionizing radiation interacts with interstellar ices.

Astrobiologists have shown that programmable DNA, used to assemble complex nanometer-scale structures can do so in a mixture of solvents that contains no water.

NASA scientists studying the origin of life have reproduced uracil, cytosine, and thymine, three key components of hereditary material, in the laboratory.

In the muddy sediments beneath the deep sea, NASA Astrobiology Institute-funded astrobiologists have found ancient communities of microbes that have remained virtually unchanged for 2.3 billion years.

Researchers using lunar regolith simulants discovered that the Moon might preserve organic matter suggesting that ices in permanently shadowed regions potentially hold the key to understanding the organic flux to the Earth-Moon system more than 3.8 billion years ago.

Asteroid search teams funded by NASA's Near-Earth Object (NEO) Observations Program found another 14 asteroids larger than one km in size with orbits that come close to Earth's vicinity. Asteroid search teams also found 1267 asteroids less than one km in size, along with four additional near-Earth comets. This brings the total known population of NEOs to 12,928 (as of 27 July 2015). The high-precision orbit predictions computed by NASA's Jet Propulsion Laboratory (JPL) show that none of these objects is likely to strike the Earth in the next century. However, 1,604 NEOs (of which 154 are larger than one km in diameter), with 94 just found this year, are in orbits that could become a hazard in the more distant future and warrant continued monitoring.

The NEO Wide-field Infrared Survey Explorer (NEOWISE) restart mission observed preliminary diameters and albedos for 9,309 asteroids in its first year. Of these, 203 are near-Earth asteroids, and 9,106 are Main Belt or Mars-crossing asteroids. Diameters can typically be derived to an accuracy of ~20% with the 3.4 and 4.6 micron data available from the NEOWISE mission; when visible light observations are also in hand, albedos can be computed with ~40-50% accuracy. NASA's Infrared Science Archive (IRSA) is the designated repository for infrared observations. IRSA has received all NEOWISE Year 1 observations. By virtue of the wavelengths it employs, as well as its survey cadence and viewing geometry, NEOWISE near-Earth object discoveries tend to be large and dark, complementing ground-based visible surveys. NEOWISE continues to operate with nearly identical performance in its 3.4 and 4.6-micron channels to that demonstrated during the Wide-field Infrared Survey Explorer (WISE) prime mission. Over 200 refereed publications have used NEOWISE data.

## WORK IN PROGRESS IN FY 2016

In pursuit of fundamental science that guides planetary exploration, the Planetary Science Research program continues to select highly rated R&A proposals that support planetary missions and goals. Planetary science is also archiving and distributing relevant mission data to the science community and the public in a timely manner.

The NEOO project supports a network of search and characterization observatories and the data processing and analysis required to understand the near-Earth population of small bodies. In accordance with the findings and recommendations of the January 2010 National Academies study on the NEO hazard, NASA continues to:

- Analyze the small body data collected by the newly reactivated WISE mission, and support increased follow-up and analysis of this data;
- Increase collection of NEO detection and characterization data by the United States Air Force's (USAF) Panoramic Survey Telescope and Rapid Reporting System (Pan-STARRS) and the newly commissioned Space Surveillance Telescope;
- Complete the prototype of a wider field survey telescope system called ATLAS, the Asteroid Terrestrial-impact Last Alert System, designed to detect smaller asteroids as they approach the Earth;
- Support the continued and enhanced operation of planetary radar capabilities at the National Science Foundation's Arecibo and NASA's Goldstone facilities; and
- Investigate both ground and space-based concepts for increasing capacity to detect, track, and characterize NEOs of all sizes.

The European Space Agency's (ESA) Rosetta mission, with NASA participation, is orbiting the Comet Churyumov-Gerasimenko. The Philae lander separated from the Rosetta orbiter and landed on the comet on November 12.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

In FY 2017 NASA is aggressively continuing an expanded NEO observation effort that will increase the detection of NEOs of all sizes by increasing the observing time on ground-based telescopes such as Pan-STARRs and the Space Surveillance Telescope, and improve their characterization using assets such as the Infra-Red Telescope Facility. The program is also supporting the study of the composition of NEOs through the collection and analyses of meteorites, as well as the analyses of samples returned by spacecraft missions.

# PLANETARY SCIENCE RESEARCH

## Program Elements

### PLANETARY SCIENCE RESEARCH AND ANALYSIS (R&A)

Planetary Science R&A enhances the scientific return from on-going and completed spaceflight missions and provides the foundation for the formulation of new scientific questions and strategies for answering those questions. R&A develops new theories and instrumentation concepts that enable the next generation of spaceflight missions. R&A funds research tasks in areas such as astrobiology and cosmo chemistry; the origins and evolution of planetary systems; the observation and characterization of extra-solar planets (i.e. exoplanets) and the atmospheres, geology, and chemistry of the solar system's bodies other than the Earth or the sun.

**Recent Achievements**

Over the last year, Planetary Science Research and Analysis has supported numerous efforts to retrieve, restore, calibrate, and archive valuable datasets from past missions and research projects. One archiving effort is adding 25-years-worth of ground-based telescopic data on comets, Kuiper belt objects, and other small solar system bodies to the Planetary Data System (PDS). Another is adding 15-years-worth of ground-based spectroscopic data on asteroids and other small bodies to the PDS. NASA is funding the effort to restore, calibrate, and archive data from Soviet-led VEGA balloon missions to Venus, which had significant inputs from France and the U.S., in order to make in-situ Venus atmospheric measurements available to the science community. NASA is calibrating and archiving a 27-year-old radar dataset of Venus from the Arecibo telescope to allow a comparison with more recent datasets to search for signs of recent volcanism or other surface changes on that planet. Through a combination of improved calibration of data from the MESSENGER spacecraft and the use of ground-based observational data, researchers are improving the global crater database and more accurately mapping the compositional and morphological variations across the surface of Mercury, and gaining a better understanding of the elemental composition of the planet. Using data from the EPOXI and Stardust-NExT flyby missions, efforts are progressing to understand the hydrogen and water production rates of their target comets, and to link geologic features of cometary nuclei to the primary forms of cometary activity. Examination of images from the WISE space telescope is allowing the extraction of orbital data for Jupiter Family Comets. Several additional PMDAP investigations are improving our knowledge of asteroids using recalibrated data from the Dawn, Hayabusa and NEAR missions that orbited their target asteroids, and from the Galileo spacecraft during its asteroid flybys. While using Magellan imagery to map the geological planet, NASA is also using the analysis of tracking data from the Magellan and Venus Express orbiters to derive a high-resolution gravity field for Venus.

### NEAR EARTH OBJECT OBSERVATIONS (NEOO)

NASA formally established a NEOO Research Program with a goal to detect and track at least 90 percent of the asteroids and comets greater than 140 meters in diameter that come within 1.3 astronomical units of the Sun (within about 30 million miles of Earth's orbit). The NEOO Program, using ground and space-based assets, looks for NEOs that have any potential to collide with Earth and do significant damage to the planet. Since NASA's search started in 1998, the program has found over 90 percent of these objects that are 1 kilometer and larger, and about 24 percent of all those larger than 140 meters in size. The program will also discover and characterize NEOs that could be viable targets for robotic and crewed exploration. This is part of NASA's response to the Asteroid Grand Challenge: to find all asteroid threats to human population and know what to do about them.

# PLANETARY SCIENCE RESEARCH

The FY 2017 request includes $6.1 million for Asteroid Impact and Deflection Assessment (AIDA), all of which is for a Double Asteroid Redirection Test (DART). DART is the kinetic impactor component of this collaborative asteroid deflection demonstration with the European Space Agency. This would be the first mission to demonstrate asteroid deflection using a kinetic impactor.

For more information on the search for NEOs, go to http://neo.jpl.nasa.gov.

### DIRECTORATE MANAGEMENT

Directorate Management supports the Robotics Alliance project, which increases interest in science, technology, engineering, and mathematics disciplines among youth in the United States. Annual activities and events expose students to challenging applications of engineering and science. The Robotics Alliance project supports national robotic competitions in which high school students' work with engineering and technical professionals from government, industry, and universities to gain hands-on experience and mentoring.

## Program Schedule

The Planetary Science Research Program will conduct its next call for research proposals as part of the Science Mission Directorate's annual Research Opportunities in Space and Earth Sciences (ROSES) research calls in 2016.

## Program Management & Commitments

| Program Element | Provider |
|---|---|
| R&A | Provider: NASA<br>Lead Center: Headquarters (HQ)<br>Performing Center(s): Ames Research Center (ARC), Glenn Research Center (GRC), Goddard Space Flight Center (GSFC), Jet Propulsion Laboratory (JPL), Johnson Space Center (JSC), Langley Research Center (LaRC), Marshall Space Flight Center (MSFC), HQ<br>Cost Share Partner(s): N/A |
| NEOO | Provider: NASA<br>Lead Center: HQ<br>Performing Center(s): HQ, GSFC, JPL, ARC<br>Cost Share Partner(s): National Science Foundation (NSF), USAF, Smithsonian Astrophysical Observatory (SAO) |

# PLANETARY SCIENCE RESEARCH

## Acquisition Strategy

The R&A budget will fund competitively selected activities from the ROSES omnibus research announcement.

### INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Quality | Planetary Science Subcommittee | 2015 | Review to assess goals and objectives of program. | Recommendation was to maintain a strong program consistent with the decadal survey. | 2016 |

# OTHER MISSIONS AND DATA ANALYSIS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Joint Robotics Program for Exploration | 10.0 | -- | **10.0** | 10.0 | 10.0 | 10.0 | 10.0 |
| Planetary Science Directed R&T | 0.0 | -- | **2.7** | 4.9 | 19.8 | 15.8 | 16.7 |
| Science Innovation Fund | 0.0 | -- | **5.0** | 6.0 | 6.0 | 6.0 | 6.0 |
| Planetary Data System | 13.7 | -- | **14.5** | 14.6 | 14.7 | 14.8 | 14.9 |
| Astromaterial Curation | 6.4 | -- | **9.1** | 9.8 | 10.0 | 10.2 | 10.4 |
| Science Data & Computing | 2.0 | -- | **2.4** | 2.5 | 2.7 | 2.7 | 2.8 |
| Rosetta | 14.3 | -- | **8.8** | 5.4 | 0.0 | 0.0 | 0.0 |
| **Total Budget** | **46.4** | -- | **52.5** | **53.2** | **63.2** | **59.5** | **60.8** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

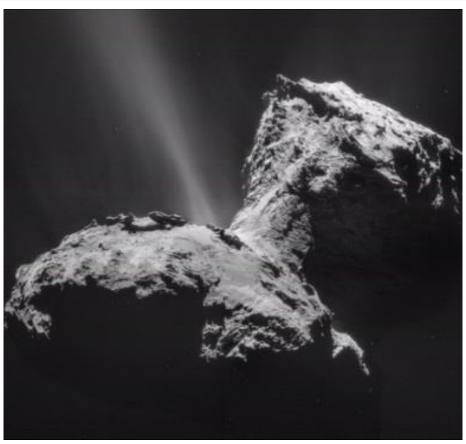


**Image of comet 67P/Churyumov-Gerasimenko taken on 31 January 2015 by Rosetta's on-board navigation camera. Credit: ESA/Rosetta/NAVCAM**

Other Missions and Data Analysis includes supporting mission functions such as Planetary Data Systems, Science Data and Computing, and Astromaterial Curation, as well as the NASA portion of the ESA Rosetta mission.

## Mission Planning and Other Projects

### JOINT ROBOTICS PROGRAM FOR EXPLORATION

This activity funds research and analysis in support of human spaceflight planning and robotic systems development. These activities will characterize exploration environments, identify hazards, and assess resources, which will inform the selection of future destinations, support the development of exploration systems, and reduce the risk associated with human exploration. NASA's SMD will jointly conduct many of these research and analysis activities with the Human Exploration and Operations Mission Directorate (HEOMD) to maximize the benefit to both science and exploration objectives, as was done successfully with the Lunar Reconnaissance Orbiter (LRO) mission.

#### Recent Achievements

The Solar System Exploration Research Virtual Institute (SSERVI), funded through the Joint Robotics Program for Exploration, had a highly productive second year of operations, producing over 160 peer-reviewed publications by its nine domestic teams, hosting numerous in-person and virtual scientific events and conducting a wide range of research projects at the intersection of human space exploration and planetary science. The SSERVI dust accelerator, housed at the University of Colorado, which studies important impact phenomena relevant to both human exploration and space weathering (damage that occurs to any object exposed to the harsh environment of outer space), set a new speed record of 117 km/sec. To allow for highly integrated scientific measurements on Earth in preparation for human and robotic missions, NASA established three field sites at various places in both the U.S. and Canada. A SSERVI scientist conducted the first field training for the new class of NASA astronauts, akin to the field training that made a big impact in the scientific results gained from Apollo. Another SSERVI scientist developed a new understanding of the electrical charging that occurs in deep space operations particularly near asteroids, which will result in safer space suits for future exploration. SSERVI increased its international presence through new partnerships with both Italy and Australia in FY 2015.

## PLANETARY SCIENCE DIRECTED RESEARCH AND TECHNOLOGY

This project funds the civil service staff that will work on emerging Planetary Science flight projects, instruments, and research. The workforce and funding will transfer to projects by the beginning of FY 2017.

## SCIENCE INNOVATION FUND

The Science Innovation Fund provides funding to NASA Centers to invest in scientific research that will enhance scientific innovation, NASA's ability to meet future missions, NASA's ability to forge new collaborations, and recruitment and retention of scientists. The purpose of the Science Innovation Fund is twofold: 1) Promote the conduct of highly innovative, exploratory, and high-risk/high return scientific research in support of the strategic direction of the Agency; and 2) Promote the vitality of the NASA Centers through strategic investments in scientific research, capabilities, and people. While this project is in the Science account, it is for use by the entire NASA science workforce, including SMD and HEOMD.

### Recent Achievements

Searching for Organics on Mars: GSFC scientists demonstrated that cosmic rays can effectively degrade amino and carbolic acids in the top 1 meter of Martian rocks or regolith within 100 million years. This result will affect where we can search for past life on Mars, as cosmic rays will degrade exposed surfaces.

Formation of ancient continental crusts: JSC scientists developed a new method for measuring the fraction of the radioactive isotope potassium 40K (the ratio of 40K/41K) which is almost 100 times more precise than previous techniques. This new high-precision technique will improve our geochronology studies of the early Earth.

Citizen Science: SIF funded a citizen science project called Disk Detective that crowdsources analysis of images from the WISE mission to efficiently search for debris disks and young stellar objects. NASA will use these results to guide future searches for exoplanets. So far, citizen scientists have logged over 1.5 million classifications with a goal of completing their first stage of analysis by the fall of 2018.

In total, SIF work has resulted in approximately 30 scientific peer-reviewed publications.

## PLANETARY DATA SYSTEM

# OTHER MISSIONS AND DATA ANALYSIS

The PDS is an online data archive. Scientists with expertise in planetary science disciplines designed the PDS, and they curate its data. The PDS furthers NASA's Planetary Science goals by efficiently collecting, archiving, and making accessible digital data produced by, or relevant to, NASA's planetary missions, research programs, and data analysis. The archives include imaging experiments, magnetic and gravity field measurements, orbit data, and various spectroscopic observations. All space-borne data from over 50 years of NASA-funded exploration of comets, asteroids, moons, and planets is publically available through the PDS archive.

### Recent Achievements

NASA completed a re-competition of the PDS archives, and established cooperative agreements for management of the various archives for the next five years.

## ASTROMATERIAL CURATION

The Astromaterials Acquisition and Curation Office at JSC curates all extraterrestrial material and space-exposed flight hardware under NASA control. Curation is an integral part of all sample return missions. Activities conducted by the Curation Office range from research into advanced curation techniques in support of future missions, sample-return-mission planning, archiving of engineering and reference materials, recovery and transport of returned materials, initial characterization of new samples, preparation and allocation of samples for research, and providing clean and secure storage for the benefit of current and future generations. Samples currently include Antarctic meteorites, cosmic dust, and returned samples from the Moon (Apollo and Luna), the Sun (solar wind captured by Genesis), a comet (Stardust), an asteroid (Hayabusa), and interplanetary dust (on space-exposed hardware). Planning and research are currently underway for future curation of samples from asteroids (OSIRIS-REx, Hayabusa2, and ARM), Mars, and comets.

## SCIENCE DATA AND COMPUTING

This project, through the National Space Science Data Center (NSSDC), preserves NASA's science data collected since the first robotic missions in the 1960s. The NSSDC also serves as the back-up archive for the PDS. In addition to being a depository that makes unique data and metadata available, the NSSDC provides the space science community with stewardship, guidance, and support so that data made available to the research community is well documented to provide independent usability.

### Recent Achievements

The NSSDC is currently working to convert many of the original data sets, which exist in analog form in their original media, to digital data sets accessible on-line by researchers.

# Operating Missions

# OTHER MISSIONS AND DATA ANALYSIS

## ROSETTA

Rosetta is an ESA-led comet rendezvous mission, with NASA participation, in its operations phase. It launched in March 2004, and is enabling scientists to look at some of the most primitive material from the formation of the solar system 4,600 million years ago. Rosetta is studying the nature and origin of comets, the relationship between cometary and interstellar material, and the implications of comets with regard to the origin of the solar system. The Rosetta spacecraft is the first to undertake long-term exploration of a comet at close quarters. It comprises a large orbiter designed to operate for a decade at large distances from the sun, and a small lander. Each of these elements carries a large number of scientific experiments and examinations designed to complete the most detailed study of a comet ever attempted. Rosetta arrived at Comet C-S in FY 2014.

### Recent Achievements

Science observation and operations are underway after Rosetta's Comet C-S orbit insertion and mapping with the lander touching down on Comet C-S in November 2014. Rosetta will orbit and study the comet until the end of FY 2016.

# DISCOVERY

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| InSight | 170.0 | 92.1 | **13.3** | 8.7 | 9.0 | 9.0 | 0.0 |
| Other Missions and Data Analysis | 89.7 | -- | **189.2** | 268.6 | 328.4 | 336.0 | 405.3 |
| **Total Budget** | **259.7** | -- | **202.5** | **277.3** | **337.4** | **345.0** | **405.3** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**All completed Discovery missions have achieved ground-breaking science, each taking a unique approach to space exploration, doing what's never been done before, and driving new technology innovations.**

NASA's Discovery program supports innovative, relatively low-cost, competitively selected Planetary Science missions. Discovery provides scientists the opportunity to identify innovative ways to unlock the mysteries of the solar system through missions to explore the planets, their moons, and small bodies such as comets and asteroids.

The Discovery program currently has two operational spacecraft: LRO and Dawn; and one flight mission in development: the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight). The program has also developed and delivered the Strofio instrument as a part of ESA's BepiColombo mission to Mercury.

### EXPLANATION OF MAJOR CHANGES IN FY 2017

In FY 2017, one or two new flight missions will be selected to enter Phase B, as a result of the Step 2 Concept Study Reports due to be completed in FY 2016. Dawn will be completing data analysis and archiving data after the completion of its mission. PSD has extended the Lunar Reconnaissance Orbiter mission through FY 2017, based upon its successful review during the last Planetary Science Senior Review. Plans for InSight are currently under development, following the delay of mission launch.

### ACHIEVEMENTS IN FY 2015

MESSENGER completed its second and final extended mission, and met all mission success criteria. The spacecraft impacted the Mercury surface as planned, on April 30, 2015, more than ten years after launch.

# DISCOVERY

Dawn arrived at Ceres in March 2015, and conducted its Survey and High Altitude Mapping Orbits around the largest main belt asteroid. Dawn completed all mission success requirements applicable for these phases of the mission.

NASA approved the InSight mission to enter Phase D. InSight completed much of its integration and environmental testing.

Data from LRO have shown that the Moon is far more dynamic than previously known and is a critical target for understanding fundamental processes that shape all solar system bodies. During FY 2015, LRO decreased its periapsis altitude over the South Pole to within ~20 km, enabling improved measurements by the Lunar Orbiter Laser Altimeter (LOLA) of the reflectance of areas near the pole that may contain surface frost. LRO has advanced the lunar geodetic grid down to meter scale accuracy (from km scale accuracy on the lunar far side prior to the mission) and has enabled the production of highly accurate maps using LRO data, such as the global set released by the USGS in FY 2015.

NASA announced five Discovery awards resulting from the 2014 Discovery Announcement of Opportunity. The missions selected for Phase A study are:

Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI), which would study the chemical composition of Venus' atmosphere during a 63-minute descent to understand the origin of the Venus atmosphere, its evolution, and why it is different from Earth and Mars.

Lucy, which would perform the first reconnaissance of the Jupiter Trojan asteroids, objects thought to hold vital clues to deciphering the history of the solar system, to determine the surface composition, physical properties, and geology of a diverse set of Trojans.

Near Earth Object Camera (NEOCam), which would survey and catalog the objects in the inner solar system to determine the origin of present-day near Earth objects and main belt asteroids. It would also determine the present distribution of organic material and volatiles, as well as discover ten times more near-Earth objects than all NEOs discovered to date.

Psyche, which would explore the origin of planetary cores by studying the metallic asteroid Psyche, directly examining the interior of a differentiated body to understand the interior of the terrestrial planets, including Earth.

Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy mission (VERITAS), which would determine what geological processes are currently operating on Venus, produce global, high-resolution topography and imaging of Venus' surface and produce the first maps of deformation and global surface composition.

## WORK IN PROGRESS IN FY 2016

The program office will establish contracts for the five Phase A studies selected in 2015, and each of the five teams will prepare and submit their Concept Study Reports for down selection to a flight mission.

The InSight mission launch in March 2016 from Vandenberg Air Force Base was cancelled due to problems with the primary instrument. Plans for the remainder of FY 2016 are currently under development.

Dawn is spiraling down to its final Low Altitude Mapping Orbit, where it will arrive by December 2015. The mission will conclude in July 2016.

LRO will continue work understanding the transport of volatiles, examining recent and ongoing surface changes and observing how the regolith (the loose material on the surface of the Moon) evolves over time. Its observations improve what we know about the interior of the Moon based on surface observations, by examining the interactions between the Moon and the space environment, the solar wind and galactic cosmic radiation. The LRO team is organizing a two volume special LRO issue in the journal Icarus, where over 50 publications are in peer review.

### KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA will select one or two new flight missions to enter Phase B.

## Program Schedule

| Date | Significant Event |
|---|---|
| Aug 2016 | Receive Phase A Concept Study Reports for five potential flight missions |
| Jan 2017 | Down selection of Investigation(s) for Flight (target) |

## Program Management & Commitments

The Planetary Missions Program Office at MSFC provides program management.

| Program Element | Provider |
|---|---|
| InSight | Provider: Lockheed Martin<br>Lead Center: JPL<br>Performing Center(s):NA<br>Cost Share Partner(s): Centre National d’Etudes Spatiales (CNES), German Aerospace Center (DLR) |
| Dawn | Provider: NA<br>Lead Center: JPL<br>Performing Center(s): NA<br>Cost Share Partner(s): DLR, Agenzia Spaziale Italiana (ASI) |
| LRO | Provider: N/A<br>Lead Center: GSFC<br>Performing Center(s): GSFC,JPL<br>Cost Share Partner(s): NA |

# DISCOVERY

| Program Element | Provider |
|---|---|
| International Missions Contributions | Provider: NA<br>Lead Center: HQ<br>Performing Center(s): JPL<br>Cost Share Partner(s): JAXA |
| Strofio | Provider: Southwest Research Institute<br>Lead Center: MSFC<br>Performing Center(s): NA<br>Cost Share Partner(s): ESA |

## Acquisition Strategy

Contracts for the newly selected Phase A awards are under development.

### INDEPENDENT REVIEWS

The Discovery Program's next review will be a Program Integration Review in 2016.

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Program Implement-ation Review (PIR) | Standing Review Board (SRB) | 2010 | Review implementation of Program | Passed | May 2016 |

# InSight

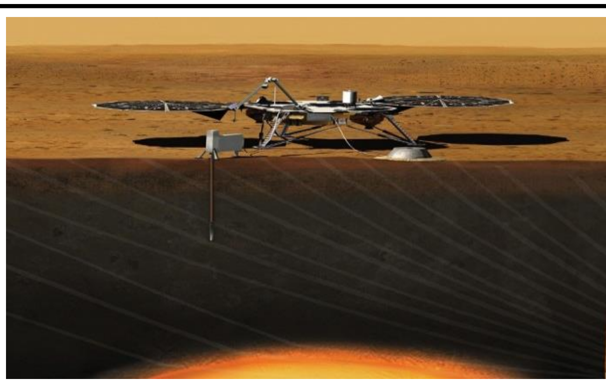
| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Prior | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 | BTC | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Formulation | 98.9 | 0.0 | 0.0 | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 98.9 |
| Development/Implementation | 292.2 | 170.0 | 79.6 | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 541.8 |
| Operations/Close-out | 0.0 | 0.0 | 12.5 | **13.3** | 8.7 | 0.0 | 0.0 | 0.0 | 0.0 | 34.5 |
| **2016 MPAR LCC Estimate** | **391.1** | **170.0** | **92.1** | **13.3** | **8.7** | **0.0** | **0.0** | **0.0** | **0.0** | **675.2** |
| **Total Budget** | **391.1** | **170.0** | **92.1** | **13.3** | **8.7** | **9.0** | **9.0** | **0.0** | **0.0** | **693.1** |
| Change from FY 2016 | | | | **-78.8** | | | | | | |
| Percentage change from FY 2016 | | | | **-85.6%** | | | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**Scientists have determined the deep structure of only one planet: Earth. To obtain vital clues to how Mars formed, InSight will deploy a German-built drill nicknamed "The Mole" to pound 16 feet into the Martian crust for thermal measurements, and a sensitive French-built seismometer to detect "Marsquakes." Through these and other instruments, scientists will be able to deduce the deep structure of Mars, which currently is a mystery.)**

## Project Purpose

InSight is a Mars lander mission to investigate fundamental issues of terrestrial planet formation and evolution with a study of the deep interior of Mars. This mission will seek to understand the evolutionary formation of rocky planets, including Earth, by investigating the crust and core of Mars. InSight will also investigate the dynamics of any Martian tectonic activity and meteorite impacts and compare this with like phenomena on Earth.

## Explanation of Major Changes in FY 2017

Due to cancellation of the March 2016 launch opportunity, plans for InSight are currently under development. Potential budget impacts are not well understood at this time and therefore are not reflected in the table above.

# INSIGHT

| Formulation | Development | Operations |
| --- | --- | --- |

## PROJECT PARAMETERS

NASA planned to launch InSight in March 2016, landing on Mars in September 2016. The InSight lander will be equipped with two science instruments that will conduct the first "check-up" of Mars in its more than 4.5 billion years, measuring its "pulse," or internal activity; its temperature; and its "reflexes" (the way the planet wobbles when it is pulled by the Sun and its moons). The science payload comprises two major instruments: the Seismic Experiment for Interior Structure (SEIS) and the Heat Flow and Physical Properties Package (HP3). SEIS will take precise measurements of quakes and other internal activity on Mars to help understand the planet's history and structure. HP3 is a self-penetrating heat flow probe that burrows up to five meters below the surface to measure how much heat is coming from Mars' core. In addition, the Rotation and Interior Structure Experiment will use the spacecraft communication system to provide precise measurements of planetary rotation. InSight will spend roughly two years (720 Earth days or 700 "sols" Martian days) investigating the deep interior of Mars. The prime mission will last two Earth years.

## ACHIEVEMENTS IN FY 2015

Following a successful Systems Integration Review (SIR) in February 2015 and KDP-D Review in March 2015 with approval to enter Phase D, InSight completed spacecraft environmental testing and integration, and began payload integration and testing.

## WORK IN PROGRESS IN FY 2016

Due to problems with the primary instrument, NAS had to cancel InSight's March 2016 launch opportunity. Assessment is under way to determine whether the instrument problems can be resolved for a possible launch in 2018.

## SCHEDULE COMMITMENTS/KEY MILESTONES

| Milestone | Confirmation Baseline Date | FY 2017 PB Request |
| --- | --- | --- |
| Launch | Mar 2016 | TBD |
| KDP-E | Apr 2016 | TBD |
| Mars Landing | Sep 2016 | TBD |
| End of Prime Mission | Sep 2018 | TBD |

# INSIGHT

| Formulation | Development | Operations |
|---|---|---|

## Development Cost and Schedule

| Base Year | Base Year Develop-ment Cost Estimate ($M) | JCL (%) | Current Year | Current Year Develop-ment Cost Estimate ($M) | Cost Change (%) | Key Milestone | Base Year Milestone Data | Current Year Milestone Data | Milestone Change (mths) |
|---|---|---|---|---|---|---|---|---|---|
| 2014 | 541.8 | 70 | 2016 | 541.8 | 0% | LRD | Mar 2016 | TBD | 0 |

*Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.*

## Development Cost Details

Due to cancellation of the March 2016 launch opportunity, plans for InSight are currently under development. The development cost details in the table below were based on the March 2016 launch date.

| Element | Base Year Development Cost Estimate ($M) | Current Year Development Cost Estimate ($M) | Change from Base Year Estimate ($M) |
|---|---:|---:|---:|
| **TOTAL:** | **541.8** | **541.8** | **0** |
| Aircraft/Spacecraft | 196.9 | 216.1 | 19.2 |
| Payloads | 18.1 | 55.1 | 37.0 |
| Systems I&T | 0.0 | 1.5 | 1.5 |
| Launch Vehicle | 159.9 | 159.9 | 0 |
| Ground Systems | 7.4 | 10.8 | 3.4 |
| Science/Technology | 7.1 | 11.2 | 4.1 |
| Other Direct Project Costs | 152.4 | 87.2 | -65.2 |

# INSIGHT

| Formulation | Development | Operations |
|---|---|---|

## Project Management & Commitments

NASA selected the InSight project through the competitive Discovery 2010 Announcement of Opportunity (AO). The principal investigator for InSight is from JPL. JPL will manage the InSight mission and will provide systems engineering, safety and mission assurance, project scientists, flight dynamics, payload management, and mission system management.

| Element | Description | Provider Details | Change from Baseline |
|---|---|---|---|
| Spacecraft | Similar in design to the Mars lander that the Phoenix mission used successfully in 2007 | Provider: Lockheed Martin<br>Lead Center: JPL<br>Performing Center(s): N/A<br>Cost Share Partner(s): N/A | N/A |
| SEIS | Will take precise measurements of quakes and other internal activity on Mars | Provider: CNES<br>Lead Center: JPL<br>Performing Center(s): N/A<br>Cost Share Partner(s): N/A | N/A |
| HP3 | A heat flow probe that will hammer 5 meters into the Martian subsurface (deeper than all previous arms, scoops, drills and probes) to measure heat emanating from the core | Provider: DLR<br>Lead Center: JPL<br>Performing Center(s): N/A<br>Cost Share Partner(s): N/A | N/A |
| Rotation and Interior Structure Experiment (RISE) | Uses the spacecraft's communication system to provide precise measurements of planetary rotation | Provider: JPL<br>Lead Center: JPL<br>Performing Center(s): N/A<br>Cost Share Partner(s): N/A | N/A |
| Launch Vehicle | Atlas V launch vehicle and related launch services | Provider: United Launch Alliance (ULA)<br>Lead Center: KSC<br>Performing Center(s): KSC<br>Cost Share Partner(s): N/A | N/A |

# INSIGHT

| Formulation | Development | Operations |
|---|---|---|

## Project Risks

| Risk Statement | Mitigation |
|---|---|
| If: If Mars environment, entry conditions, or spacecraft behavior is not as anticipated,<br>Then: Landing may not be successful. | Project will build comprehensive simulations of landing scenarios and test entry descent and landing systems, including independent verification of analysis. The project employs personnel who conducted previous successful Mars landings. The project will certify potential landing ellipses for elevation, slopes, and rock abundance. The project will use validated environmental models informed by atmospheric measurements from the previous three decades of observations at Mars. |
| If: Deployment of SEIS is not successful,<br>Then: The science objectives will be compromised. | The project will conduct extensive testing of deployments in test beds, including fault scenarios. Test beds will also be available during mission operations to verify actual deployment moves, with ground verification deployed at each step during operations. The project will certify potential landing ellipses for elevation, slopes, and rock abundance. |

## Acquisition Strategy

NASA selected the InSight mission through a competitive Discovery Program 2010 AO and a down selection in September 2012. All major acquisitions are in place.

### MAJOR CONTRACTS/AWARDS

A contract with Lockheed Martin is in place for the flight system.

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Spacecraft | Lockheed Martin | Denver, CO |

# INSIGHT

| Formulation | Development | Operations |
| --- | --- | --- |

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
| --- | --- | --- | --- | --- | --- |
| Perform-ance | SRB | Feb 2015 | SIR | InSight successfully met the criteria for SIR and the PMC decision authority approved the project to continue to the next phase at KDP-D. | N/A |
| Perform-ance | SRB | Dec 2015 | ORR | TBD | Feb 2016 |
| Perform-ance | JPL System Review Team and SRB | Feb 2016 | FRR | TBD | N/A |

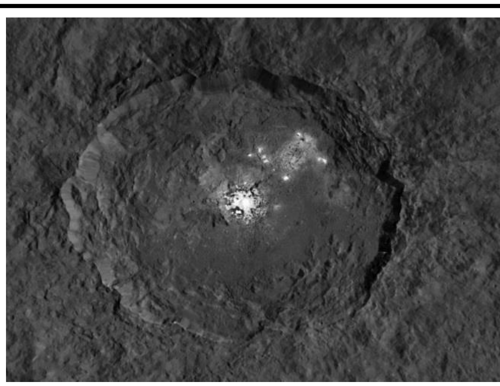
# OTHER MISSIONS AND DATA ANALYSIS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Strofio | 0.3 | -- | **0.6** | 0.7 | 0.7 | 0.6 | 0.6 |
| International Mission Contributions (IMC) | 1.9 | -- | **1.8** | 2.3 | 3.3 | 2.4 | 1.9 |
| Planetary Missions Program Office | 0.0 | -- | **16.4** | 16.7 | 17.9 | 17.2 | 17.0 |
| Discovery Future | 25.0 | -- | **136.1** | 212.1 | 289.9 | 300.9 | 371.4 |
| Discovery Management | 7.6 | -- | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| Discovery Research | 9.5 | -- | **13.3** | 16.8 | 16.6 | 14.9 | 14.4 |
| Lunar Reconnaissance Orbiter | 19.8 | -- | **20.0** | 20.0 | 0.0 | 0.0 | 0.0 |
| Dawn | 17.2 | -- | **1.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| MESSENGER | 6.0 | -- | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| Gravity Recovery and Interior Laboratory | 2.4 | -- | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| **Total Budget** | **89.7** | **--** | **189.2** | **268.6** | **328.4** | **336.0** | **405.3** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**Enigmatic bright spots in Occator crater on the dwarf planet Ceres as seen by the Dawn spacecraft from its high-altitude mapping orbit of 915 miles (1470 kilometers). Based on the absence of other craters within it, Occator is a very recent 56-mile (90-kilometer) wide impact crater. The intense brightness of the persistent spots is due to the presence of a highly reflective material on the surface, possibly a mineral salt or pure water ice. The smooth crater floor indicates possible flowing material – either impact debris or post-impact melting or volcanism.**

Other Missions and Data Analysis funds research and analysis, management activities, operations of active missions, small projects, and international collaborations. It includes missions of opportunity (e.g., the instrument Strofio; operating missions (Dawn, LRO); missions whose operations have ceased but data analysis continues (Gravity Recovery and Interior Laboratory and MESSENGER); competed research; funding for future mission selections; and program management activities.

## Mission Planning and Other Projects

### STROFIO

Strofio is a unique mass spectrometer, part of the SERENA suite of instruments that will fly onboard the ESA BepiColombo spacecraft, scheduled for launch in 2016. Strofio will determine the chemical composition of Mercury's surface, providing a powerful tool to study the planet's geologic history.

# OTHER MISSIONS AND DATA ANALYSIS

### Recent Achievements

Project support to ESA's spacecraft level testing continues in 2016 to prepare the spacecraft for launch by February 2017.

## INTERNATIONAL MISSION CONTRIBUTIONS (IMC)

There are more scientifically interesting destinations across the solar system than any one country's program can quickly undertake. NASA works closely with the planetary science programs of other space agencies to find opportunities to participate in each other's missions. Under the International Mission Contributions, NASA funds instruments and scientific investigators, and will provide navigation and data relay services, in exchange for participation. International missions in FY 2017 include the Japanese Space Agency's Hayabusa-2 and Akatsuki (Venus Climate Orbiter) missions. The Akatsuki mission will attempt orbit insertion at the beginning of FY 2016 and study Venus for two years. Hayabusa-2, which launched in 2016, will arrive at asteroid Ryugu in 2020 and capture and return a sample.

## PLANETARY MISSIONS PROGRAM OFFICE

Discovery Management fully funds the Planetary Missions Program Office at the MSFC, which manages all of the Planetary Science flight projects that are not part of the Mars Exploration Program. This currently includes the Discovery and New Frontiers programs, and the JUICE and Europa projects. Discovery Management includes support for the day-to-day efforts of the Mission Managers and business office, as well as standing review boards and external technical support as needed for the projects. It also funds work at the LaRC's office for Mission Assessments to support the mission selection process including the development of AO and the formation and operations of independent panel reviews to evaluate mission proposals. The project supports the standing review boards that ensure that all missions in development undergo rigorous Life Cycle Reviews.

## DISCOVERY FUTURE

Discovery Future funds new missions selected through the Announcement of Opportunity process, specific technology investments to enable future missions, and small missions of opportunity. The Discovery AO released in November 2014, will result in a mission selected to launch no later than December 2021, and possibly a second mission to launch approximately 2 years later. Technology development includes NASA'S Evolutionary Xenon Thrusters and Power Processing Units. Future competitive opportunities are under evaluation for both planetary cubesats and the next planetary balloon mission of opportunity planned for FY 2017.

### Recent Achievements

NASA selected five mission proposals for Phase A studies.

## DISCOVERY RESEARCH

Discovery Research funds analysis of archived data from Discovery missions, and supports participating scientists for the MESSENGER, Dawn, InSight and GRAIL missions. Discovery Research gives the research community access to samples and data and allows research to continue for many years after mission completion. Scientists in the U.S. planetary science community submit research proposals that NASA selects through competitive peer review.

Discovery Research also funds the analysis of samples returned to the Earth by the Stardust and Genesis missions as well as the development of new analysis techniques for samples returned by future missions.

### Recent Achievements

Analytical and scientific advances continue to be made that enhance the value of past sample-return missions such as Stardust, Genesis, and Hayabusa and will enable advanced research on future returned samples anticipated from OSIRIS-REx and Hayabusa2. We continue to learn about the origin of comets, such as the one visited by Stardust, which in turn tells us about the origin of the entire solar system. Multiple studies have now shown a close relationship between materials formed in the inner solar system and those found in comets, which come from the outer solar system. Transport of material throughout the early solar system seems to have been a widespread process. Careful searches of Stardust collectors are discovering an increasing number of interstellar grains among the more common solar system materials, telling about the solar system’s environment in the galaxy. New methods of cleaning Genesis samples are opening up the possibility of analyzing more elements and isotopes in the solar wind, furthering our understanding of the Sun and the origin of the solar system. Analytical advances in mass spectrometry, spectroscopy, and synchrotron x-ray microscopy are opening new areas of research into studies of returned samples, and continue to improve our abilities to analyze small precious samples of all kinds.

# Operating Missions

## LUNAR RECONNAISSANCE ORBITER (LRO)

Pending a successful outcome from the next senior review, LRO will acquire new data from the full LRO instrument suite to address compelling science questions to advance our evolving understanding of the dynamic nature of the Moon. The LRO project is exploring orbit options that will maximize the science return from all instruments for these observations.

### Recent Achievements

LRO results have shown that the Moon is far more dynamic than previously thought, and is a critical target for understanding fundamental processes that shape all solar system bodies. Prior to LRO, we thought that lunar volcanism ended billions of years ago, but LRO results show small volcanic areas that are 50 to 100 million years old, perhaps even younger. LRO measurements of polar temperatures, surface frost in permanently shadowed craters, and hydrogen in the upper few feet of the lunar surface show unexpected distributions of lunar volatiles, suggesting that water ice and other volatiles migrate in dynamic ways or that other factors control their distribution, raising questions for further investigation. LRO data also shows the effects of new impact craters on the Moon's surface, constraining the size and flux of objects in near-Earth space.

# OTHER MISSIONS AND DATA ANALYSIS

## DAWN

Dawn is completing its journey to the two oldest and most massive bodies in the main asteroid belt between Mars and Jupiter. By closely orbiting asteroid Vesta and the dwarf planet Ceres with the same set of instruments, Dawn has the unique capability to compare and contrast these bodies, enabling scientists to answer questions about the formation and evolution of the solar system. Their surfaces preserve clues to the solar system's first 10 million years, along with alterations since that time, allowing Dawn to investigate both the origin and the current state of the main asteroid belt. Launched in September 2007, Dawn reached Vesta in July 2011, left in August 2012, and arrived at Ceres in March 2015.

Dawn mission data revealed the rugged topography and complex textures of the asteroid Vesta's surface. Soon other pieces of data, such as the chemical composition, interior structure, and geologic age, will help scientists understand the history of this remnant protoplanet and its place in the early solar system.

### Recent Achievements

The Dawn spacecraft gently settled into orbit at the dwarf planet Ceres in early March 2015 to begin its 16-month study of this largest object in the main asteroid belt. Early images revealed a heavily cratered surface and enigmatic bright spots. The mission has shown that the surface is dominated by clay-like minerals with little or no obvious ice, which has scientists rethinking the formation and evolution history and the internal structure of this small world. The intense brightness of the persistent spots is due to the presence of a highly reflective material on the surface, possibly a mineral salt or pure water ice. To enhance the science return from the mission, the project added nine new Guest Investigators to the Dawn science team. This 3-year program allows investigators from outside the spacecraft team to participate in science operations through the end of the mission, to conduct studies of the interior of Ceres based on crater morphology and other surface features, its volatile content and surface mineralogy, and mapping of geologic features.

# NEW FRONTIERS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| | | | | Notional | | | |
| Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer (OSIRIS-REx) | 209.8 | 189.7 | **44.0** | 38.1 | 43.1 | 27.7 | 16.5 |
| Other Missions and Data Analysis | 76.2 | -- | **100.0** | 43.5 | 47.6 | 115.1 | 217.5 |
| **Total Budget** | **286.0** | **--** | **144.0** | **81.6** | **90.7** | **142.8** | **234.0** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

**The New Frontiers Program seeks to contain total mission cost and development time and improve performance with validated new technologies, efficient management, and control of design, development, and operations costs while maintaining a strong commitment to flight safety. The program objective is to launch high-science-return planetary science investigations twice per decade.**

The New Frontiers program explores our solar system with medium-class spacecraft missions. Within the New Frontiers program, possible mission destinations and the science goals for each competitive opportunity are limited to specific science targets announced for the competition.

The program is currently comprised of three missions: two operating missions (New Horizons and Juno), and one under development, the Origins Spectral Interpretation Resource Identification and Security-Regolith Explorer (OSIRIS-REx).

The New Horizons mission will help us understand worlds at the edge of the solar system having completed the first-ever reconnaissance of Pluto and Charon, and with a potential new mission to one of the Kuiper Belt Objects.

Juno is a mission to Jupiter that will significantly improve our understanding of the origin and evolution of the gas giant planet. Juno will help us better understand the formation of planets and the origins of our solar system.

OSIRIS-REx will bring pristine samples from a carbon-rich asteroid to study and analyze on Earth. This will increase our understanding of planet formation and the origin of life. In addition to its science objectives, OSIRIS-REx will improve our knowledge of how to operate human and robotic missions safely, in close proximity to a large NEO. This knowledge will provide significant insight for both the future human mission to an asteroid, and for potential planetary defense strategies.

Potential future missions identified by the National Academies include Venus in Situ Explorer, Saturn Probe, Trojan Tour and Rendezvous, the Comet Surface Sample Return, Lunar South Pole-Aitken Basin Sample Return, Io Observer, and Lunar Geophysical Network.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Mandatory Budget Authority** | -- | -- | 40.0 | -- | -- | -- | -- |

In January 2017, NASA will release the announcement of opportunity for the next New Frontiers mission. The announcement adds a new target for Ocean Worlds, specifically soliciting missions focused on the search for signs of extant life and/or characterizing the potential habitability of Titan or Enceladus.

New Frontiers is supported in part with mandatory funding (see table, above). The mandatory investment includes $40 million for the New Frontiers Future Mission project, in support of the restoration of the schedule for the next New Frontiers announcement of opportunity and to extend the New Horizons and Juno missions, contingent on the outcome of the next Senior review.

# ORIGINS-SPECTRAL INTERPRETATION-RESOURCE IDENTIFICATION-SECURITY-REGOLITH EXPLORER (OSIRIS-REX)

| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Prior | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 | BTC | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Formulation | 144.3 | 0.0 | 0.0 | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 144.3 |
| Development/Implementation | 296.6 | 209.8 | 180.7 | **13.3** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 700.4 |
| Operations/Close-out | 0.0 | 0.0 | 9.0 | **30.7** | 38.1 | 43.1 | 27.7 | 16.5 | 47.5 | 212.6 |
| **2016 MPAR LCC Estimate** | **440.9** | **209.8** | **189.7** | **44.0** | **38.1** | **43.1** | **27.7** | **16.5** | **47.5** | **1057.3** |
| **Total Budget** | **440.9** | **209.8** | **189.7** | **44.0** | **38.1** | **43.1** | **27.7** | **16.5** | **47.5** | **1057.2** |
| Change from FY 2016 | | | | **-145.7** | | | | | | |
| Percentage change from FY 2016 | | | | **-76.8%** | | | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**Asteroids are leftovers formed from the cloud of gas and dust -- the solar nebula -- that collapsed to form our sun and the planets about 4.5 billion years ago. As such, they contain the original material from the solar nebula, which can tell us about the conditions of our solar system's birth. In sampling the near Earth asteroid Bennu in 2019, OSIRIS-REx will be opening a time capsule from the birth of our solar system.**

## PROJECT PURPOSE

The OSIRIS-REx spacecraft will travel to (101955) Bennu, a near-Earth carbonaceous asteroid formerly designated 1999 RQ36, study the asteroid in detail, and bring back a sample (at least 60 grams or 2.1 ounces) to Earth. This sample will yield insight into planet formation and the origin of life, and the data collected at the asteroid will aid in understanding asteroids that can collide with Earth. This mission will also measure the Yarkovsky effect on a potentially hazardous asteroid and measure the asteroid properties that contribute to this effect. By describing the integrated global properties of a primitive carbonaceous asteroid, this mission will allow for direct comparison with ground-based telescopic data of the entire asteroid population.

# ORIGINS-SPECTRAL INTERPRETATION-RESOURCE IDENTIFICATION-SECURITY-REGOLITH EXPLORER (OSIRIS-REX)

| Formulation | Development | Operations |
|---|---|---|

The Yarkovsky effect is a small force caused by the Sun on an asteroid, as it absorbs sunlight and re-emits that energy as heat. The small force adds up over time, but it is uneven due to an asteroid's shape, wobble, surface composition, and rotation. For scientists to predict an Earth-approaching asteroid's path, they must understand how the effect will change its orbit.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## PROJECT PARAMETERS

OSIRIS-REx will launch by October 2016, encountering the primitive, near-Earth asteroid Bennu in 2018. The mission will study the asteroid for about one year, globally mapping the surface from distances of about three miles to less than half a mile, before acquiring the sample. The spacecraft cameras and instruments will photograph the asteroid and measure its surface topography, composition, and thermal emissions. Radio science will provide mass and gravity field maps. This information will help the mission team select the most promising sample site, from which it will collect and return to Earth at least 60 grams of pristine material from the target asteroid. The spacecraft will remain near the asteroid for almost another two years before beginning its return to Earth. The sample return will use a capsule similar to the one that returned the sample of Comet 81P/Wilt on the Stardust spacecraft. This will allow the sample to return and land at the Utah Test and Training Range in September 2023. NASA will transport the capsule to JSC for processing, analysis, and curation at a dedicated research facility. JSC will make subsamples available for research to the worldwide science community.

## ACHIEVEMENTS IN FY 2015

On April 15, 2015, OSIRIS-REx successfully completed its KDP-D. The science instrument teams for OCAMS, OTES, and OVIRS have delivered the instruments, and spacecraft assembly began.

## WORK IN PROGRESS IN FY 2016

OSIRIS-REx will complete integration and testing in FY 2016. September of 2016 is the scheduled launch, with a launch window that extends into early October 2016.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

In FY 2017, the project will enter into Phase E. OSIRIS-REx will be in the early stages of its outbound cruise to the asteroid Bennu. In September of 2017, OSIRIS-REx will fly by the Earth, using the Earth's gravity to adjust its path to Bennu. OSIRIS-REx will take advantage of this flyby to obtain calibration observations of the Earth and Moon.

# ORIGINS-SPECTRAL INTERPRETATION-RESOURCE IDENTIFICATION-SECURITY-REGOLITH EXPLORER (OSIRIS-REX)

| Formulation | Development | Operations |
|---|---|---|

## SCHEDULE COMMITMENTS/KEY MILESTONES

| Milestone | Confirmation Baseline Date | FY 2017 PB Request |
|---|---|---|
| KDP-D | Mar 2015 | Mar 2015 |
| Launch | Oct 2016 | Oct 2016 |
| KPD-E | Oct 2016 | Oct 2016 |
| Earth flyby | Sep 2017 | Sep 2017 |
| Sample Return to Earth | Sep 2023 | Sep 2023 |
| KDP-F | Oct 2023 | Oct 2023 |
| End of Prime Mission (Completion of Project Sample Analysis) | Sep 2025 | Sep 2025 |

## Development Cost and Schedule

| Base Year | Base Year Develop-ment Cost Estimate ($M) | JCL (%) | Current Year | Current Year Develop-ment Cost Estimate ($M) | Cost Change (%) | Key Milestone | Base Year Milestone Data | Current Year Milestone Data | Milestone Change (mths) |
|---|---|---|---|---|---|---|---|---|---|
| 2014 | 778.6 | 70 | 2016 | 700.4 | -10% | LRD | Oct 2016 | Oct 2016 | 0 |

*Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.*

# ORIGINS-SPECTRAL INTERPRETATION-RESOURCE IDENTIFICATION-SECURITY-REGOLITH EXPLORER (OSIRIS-REX)

| Formulation | Development | Operations |
|---|---|---|

## Development Cost Details

| Element | Base Year Development Cost Estimate ($M) | Current Year Development Cost Estimate ($M) | Change from Base Year Estimate ($M) |
|---|---|---|---|
| **TOTAL:** | **778.6** | **700.4** | **-78.2** |
| Aircraft/Spacecraft | 220.2 | 265.8 | 45.6 |
| Payloads | 32.2 | 46.8 | 14.6 |
| Systems I&T | 24.9 | 24.2 | -0.7 |
| Launch Vehicle | 234 | 183.5 | -50.4 |
| Ground Systems | 34.3 | 42.8 | 8.5 |
| Science/Technology | 17.8 | 18.6 | -0.8 |
| Other Direct Project Costs | 215.3 | 118.7 | -96.6 |

## Project Management & Commitments

NASA selected the OSIRIS-REx project through the New Frontiers 2009 AO. The principal investigator is from the University of Arizona and delegated day-to-day management of the project to NASA's GSFC.

| Element | Description | Provider Details | Change from Baseline |
|---|---|---|---|
| Spacecraft | MAVEN heritage spacecraft bus, Stardust heritage Sample Return Capsule (SRC), and innovative Touch and Go Sample Acquisition Mechanism (TAGSAM) | Provider: Lockheed Martin<br>Lead Center: GSFC<br>Performing Center(s): GSFC<br>Cost Share Partner(s): N/A | N/A |
| Launch Vehicle | Atlas V launch vehicle and related launch services | Provider: United Launch Alliance (ULA)<br>Lead Center: KSC<br>Performing Center(s): KSC<br>Cost Share Partner(s): N/A | N/A |

# ORIGINS-SPECTRAL INTERPRETATION-RESOURCE IDENTIFICATION-SECURITY-REGOLITH EXPLORER (OSIRIS-REX)

| Formulation | Development | Operations |
|---|---|---|

| Element | Description | Provider Details | Change from Baseline |
|---|---|---|---|
| OSIRIS-REx Camera Suite (OCAMS) | OCAMS is comprised of multiple cameras (PolyCam, MapCam, SamCam) with a common Camera Control Module (CCM) | Provider: University of Arizona<br>Lead Center: N/A<br>Performing Center(s): N/A<br>Cost Share Partner(s): N/A | N/A |
| OSIRIS-REx Thermal Emission Spectrometer (OTES) | Thermal Emission Spectrometer with significant flight heritage from Mars Exploration Rover Mini-TES and MO/MGS TES instruments | Provider: Arizona State University<br>Lead Center: GSFC<br>Performing Center(s): GSFC<br>Cost Share Partner(s): N/A | N/A |
| OSIRIS-REx Visible and Infrared Spectrometer (OVIRS) | Visible and Infrared Spectrometer with flight heritage from Landsat TIRS (focal plane electronics), Juno (electronics box), OCO (detectors), and New Horizons LEISA (Linear Variable Filter) Instruments | Provider: GSFC<br>Lead Center: GSFC<br>Performing Center(s): GSFC<br>Cost Share Partner(s): N/A | N/A |
| OSIRIS-REx Laser Altimeter (OLA) | Dual laser altimeter with heritage from XSS-11 and Phoenix Mars Lander lidars | Provider: MacDonald, Dettwiler and Associates Ltd. (MDA)<br>Lead Center: Canadian Space Agency (CSA)<br>Performing Center(s): CSA<br>Cost Share Partner(s): CSA | N/A |
| Regolith X-ray Imaging Spectrometer (REXIS) | Instrument to observe x-ray fluorescence induced by solar x-rays using a coded aperture for imaging with a spectrometer to determine elemental composition | Provider: Massachusetts Institute of Technology (MIT)<br>Lead Center: GSFC<br>Performing Center(s): GSFC<br>Cost Share Partner(s): N/A | N/A |

# ORIGINS-SPECTRAL INTERPRETATION-RESOURCE IDENTIFICATION-SECURITY-REGOLITH EXPLORER (OSIRIS-REX)

| Formulation | Development | Operations |
|---|---|---|

## Project Risks

| Risk Statement | Mitigation |
|---|---|
| If: The Guidance, Navigation, and Control (GNC) Lidar is not ready for integration onto the spacecraft by March 2016,<br><br>Then: The spacecraft costs will substantially increase in order to accommodate a late delivery, and ultimately the launch readiness could be missed | Careful management and monitoring of progress of GNC Lidar supplier. A near-flight quality ATLO Test Unit installed on the spacecraft allows environmental testing to continue. The project has updated the ATLO budget and schedule to accommodate integration of the flight units in March 2016. |
| If: Baseline GNC Lidar altimetry method does not work at the asteroid,<br><br>Then: We do not get sample to meet mission success | Development of back-up capability using Natural Feature Tracking |

## Acquisition Strategy

All major acquisitions are in place. NASA competitively selected OSIRIS-REx on May 25, 2011 under the third New Frontiers Program AO.

### MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Spacecraft, Integration and Test | Lockheed Martin Space Systems Company (LMSSC) | Denver, CO |
| Payload – OCAMS Instrument | University of Arizona | Tucson, AZ |
| Payload – OTES Instrument | Arizona State University | Tempe, AZ |
| Ground System – Science Processing and Operations Center (SPOC) | University of Arizona | Tucson, AZ |

# ORIGINS-SPECTRAL INTERPRETATION-RESOURCE IDENTIFICATION-SECURITY-REGOLITH EXPLORER (OSIRIS-REX)

| Formulation | Development | Operations |
|---|---|---|

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Launch Vehicle and Services | ULA | Cape Canaveral, FL |

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | SRB | Feb 2015 | SIR | OSIRIS-REx successfully met the requirements for SIR. | Jun 2016 |
| Perform-ance | SRB | Jun 2016 | ORR | | Aug 2016 |
| Perform-ance | GSFC System Review Team (GSRT) | Aug 2016 | FRR | | N/A |

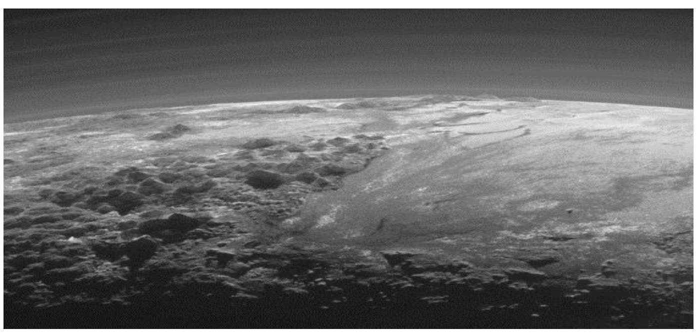
# OTHER MISSIONS AND DATA ANALYSIS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| New Frontiers Future Missions | 12.0 | -- | **42.6** | 12.0 | 28.1 | 90.2 | 203.5 |
| New Frontiers Research | 0.0 | -- | **4.3** | 5.0 | 7.5 | 12.9 | 14.0 |
| New Horizons | 28.8 | -- | **14.0** | 12.0 | 12.0 | 12.0 | 0.0 |
| Juno | 35.4 | -- | **39.1** | 14.5 | 0.0 | 0.0 | 0.0 |
| **Total Budget** | **76.2** | **--** | **100.0** | **43.5** | **47.6** | **115.1** | **217.5** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**Just 15 minutes after its closest approach to Pluto on July 14, 2015, NASA's New Horizons spacecraft looked back toward the sun and captured a near-sunset view of the rugged, icy mountains and flat ice plains extending to Pluto's horizon. The mountains of Pluto are thought to be made of water ice, which is one of the few materials on Pluto that is strong enough at the extremely low temperatures to form the steep slopes of the huge mountains. The smooth expanse of the informally named Sputnik Planum (right) is flanked to the west (left) by rugged mountains up to 11,000 feet (3,500 meters) high, including the informally named Norgay Montes in the foreground and Hillary Montes on the skyline.**

New Frontiers Other Missions and Data Analysis supports operating New Frontiers missions (New Horizons, Juno), analysis of data from those missions, as well as preparation for future missions.

## Mission Planning and Other Projects

### NEW FRONTIERS FUTURE MISSIONS

New Frontiers Future supports technology development for future missions, and provides the funding required for the next Announcement of Opportunity (AO). NASA plans to release the fourth New Frontiers AO in early FY 2017. Mission selection will occur approximately 2 years after the release of the AO.

### NEW FRONTIERS RESEARCH

New Frontiers Research funds analysis of archived data from New Frontiers missions. New Frontiers Research gives the research community access to samples and data and allows research to continue for many years after mission completion. This allows the maximum science return from each of the missions. Scientists in the U.S. planetary science community submit research proposals that NASA selects through competitive peer review. NASA will select new research in 2017, using the New Horizons mission data returned from Pluto.

## Operating Missions

### NEW HORIZONS

New Horizons is the first scientific investigation to obtain a close look at Pluto and its moons Charon, Nix, Hydra, Kerberos, and Styx (scientists discovered the last four moons after the spacecraft's launch in 2006). Scientists aim to find answers to basic questions about the surface properties, geology, interior makeup, and atmospheres on these bodies, the last in the solar system visited by a spacecraft.

New Horizons launched on January 19, 2006. It successfully encountered Pluto in July 2015. The spacecraft will next venture deeper into the Kuiper Belt, and as part of a potential extended mission, study one of the icy mini-worlds in this region approximately two billion miles beyond Pluto's orbit. The project has completed the maneuvers required to flyby Kuiper Belt Object 2014MU69 in January 2019.

To get to Pluto, which is three billion miles from Earth, in just 9.5 years, the spacecraft flew by the dwarf planet and its five moons in 2015 at a velocity of about 27,000 miles per hour. The instruments on New Horizons started taking data on Pluto and Charon six months before arrival. About three months from the closest approach, when Pluto and its moons were about 65 million miles away, the instruments began taking measurements and began to make the first maps of these bodies.

When the New Horizons spacecraft was closest to Pluto, it took a variety of scientific observations, including close-up pictures in both visible and near-infrared wavelengths. These first images should depict surface features as small as 200 feet across and bring a plethora of new discoveries. It will take over a year to downlink all of the data gathered during the flyby of Pluto.

#### Recent Achievements

The New Horizons probe has lifted the veil on Pluto. On July 14, New Horizons performed the first-ever flyby of the faraway dwarf planet, zooming within 7,800 miles (12,500 kilometers) of its frigid surface. The close encounter is giving researchers their first up-close looks at Pluto, which has remained mysterious since its 1930 discovery.

### JUNO

Juno will conduct an in-depth study of Jupiter, the most massive planet in the solar system. Juno's instruments will seek information from deep in Jupiter's atmosphere, enabling scientists to understand the fundamental processes of the formation and early evolution of the solar system. Juno successfully launched on August 5, 2011 as scheduled and within the budget allocated for development of this mission. Juno will be the first solar-panel powered spacecraft to orbit the giant planet beginning in July 2016.

# OTHER MISSIONS AND DATA ANALYSIS

During its sixteen month science operations mission, Juno, with the first-ever polar orbit of Jupiter, will complete 33 fourteen-day-long orbits and will sample Jupiter's full range of latitudes and longitudes. From its polar perspective, Juno combines remote sensing observations to explore the polar magnetosphere and determine what drives Jupiter's remarkable auroras. Juno has an onboard camera to produce images and it will provide unique opportunities to engage the next generation of scientists.

## Recent Achievements

Juno continues towards its planned encounter with Jupiter on July 4, 2016.

# MARS EXPLORATION

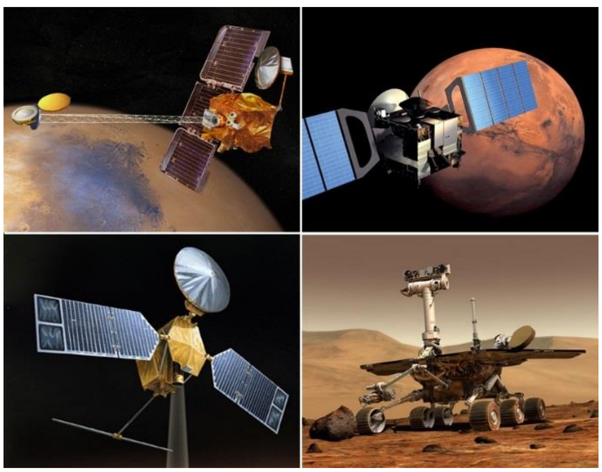
## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Mars Rover 2020 | 103.6 | -- | **377.5** | 409.0 | 381.0 | 322.0 | 140.0 |
| Other Missions and Data Analysis | 201.4 | -- | **207.3** | 179.8 | 184.0 | 176.4 | 139.9 |
| **Total Budget** | **305.0** | -- | **584.8** | **588.8** | **565.0** | **498.4** | **279.9** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*



**Every time we feel close to understanding Mars, new discoveries send us straight back to the drawing board to revise existing theories. We've discovered that today's Martian wasteland hints at a formerly volatile world where volcanoes once raged, meteors plowed deep craters, and flash floods rushed over the land. Mars continues to throw out new enticements with each landing or orbital pass made by our spacecraft.**

The Mars Exploration Program seeks to understand when Mars was habitable, is Mars habitable today, or can it be a habitable world in the future, and whether it ever supported life. As the most Earth-like planet in the solar system, Mars has a landmass approximately equivalent to the Earth's as well as many of the same geological features, such as riverbeds, past river deltas, and volcanoes. Mars also has many of the same "systems" that characterize Earth, such as air, water, ice, and geology that all interact to produce the Martian environment.

The four broad, overarching goals for Mars Exploration are to:

- Determine if life ever arose on Mars;
- Characterize the climate of Mars;
- Characterize the geology of Mars; and
- Prepare for human exploration.

Today, our robotic scientific explorers are paving the way. Together, humans and robots will pioneer Mars and the solar system.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Mandatory Budget Authority** | -- | -- | **29.0** | -- | -- | -- | -- |

# MARS EXPLORATION

Given the sustained good health of our oldest orbital and surface assets (Odyssey, Mars Express, and Opportunity), NASA plans to submit to Senior Review extended science operations proposals for consideration. The FY 2017 budget supports continued operations of these missions at their current levels.

Mars Exploration is supported in part with mandatory funding (see table, above). The mandatory investment includes $13.7 million for Mars Exploration Rover 2003/ Opportunity, $12.7 million for Mars Odyssey 2001, and $2.6 million for Mars Express, in support of continued extended operations.

## ACHIEVEMENTS IN FY 2015

On October 19, 2014, the Comet Siding Spring made its closest approach to Mars. The suite of Mars missions were able to take advantage of a unique and unexpected science opportunity for close study of a visitor from the edge of the solar system, along with its possible effects on Mars' atmosphere. Dust detected from the comet vaporized high in the atmosphere; the electron density of the ionosphere on the planet's night side was five to 10 times higher than usual; and the comet itself was 1.2 miles across and had a rotation period of eight hours.

Curiosity determined that river and lake deposits form the base of Mt. Sharp and are a result of an environment enabling substantial bodies of water to persist on the surface of Mars.

The Mars Reconnaissance Orbiter detected hydrated perchlorates in association with dark streaks that seasonally form on steep slopes of Mars. These salts significantly lower the freezing point of water and help explain these recurring flow features, leaving open the question of whether the water is absorbed from the atmosphere or from a subsurface source.

The Mars 2020 mission completed mission definition and accommodation activities and formally entered Phase B of Formulation in May 2015.

## WORK IN PROGRESS IN FY 2016

All operating Mars missions will undergo a Senior Review to determine the scientific benefit of extending their operations. Senior Review permitting, Curiosity will continue its exploration of Mars' transition to a drier planet as the rover examines younger sedimentary layers heading up Mt. Sharp and the orbital missions, MRO and Odyssey will extend their investigations of inter-annual variability.

MAVEN will complete its prime mission early in FY 2106 and extend its measurements to a full Mars year, gaining broad seasonal coverage of the processes affecting the upper atmosphere.

The Mars 2020 rover mission will undergo PDR and the confirmation review process.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

MOMA will be completed and shipped for integration into the 2018 ExoMars mission.

Mars 2020 will be in Phase C/D on implementation.

## Program Management & Commitments

| Program Element | Provider |
|---|---|
| Mars Rover 2020 | Provider: JPL<br>Lead Center: JPL<br>Performing Center(s): JPL, GSFC<br>Cost Share Partner(s): CNES; Norwegian Forsvarets Forskning Institute (FFI); Center for the Development of Industrial Technology (CDTI) and the National Institute of Aerospace Technology (INTA) of Spain |
| MOMA-MS | Provider: GSFC<br>Lead Center: GSFC<br>Performing Center(s): GSFC<br>Cost Share Partner(s): N/A |
| MSL | Provider: JPL<br>Lead Center: JPL<br>Performing Center(s): JPL, GSFC<br>Cost Share Partner(s): Canadian Space Agency, Centro de Astrobiología, Federal Space Agency of Russia |
| MAVEN | Provider: GSFC<br>Lead Center: GSFC<br>Performing Center(s): JPL, GSFC<br>Cost Share Partner(s): N/A |
| Mars Reconnaissance Orbiter (MRO) | Provider: JPL<br>Lead Center: JPL<br>Performing Center(s): JPL<br>Cost Share Partner(s): Agenzia Spaziale Italiana |
| Mars Exploration Rover (MER)/Opportunity | Provider: JPL<br>Lead Center: JPL<br>Performing Center(s): JPL<br>Cost Share Partner(s): Canadian Space Agency |
| Odyssey | Provider: JPL<br>Lead Center: JPL<br>Performing Center(s): JPL<br>Cost Share Partner(s): N/A |

## Acquisition Strategy

NASA is acquiring the spacecraft and flight systems for the Mars 2020 mission through JPL and the radioisotope power system through the Department of Energy (DOE), taking advantage of the previous investment in the MSL project to maximize heritage. By using contracts existing from the MSL project to procure new versions of the as-flown hardware, JPL plans to achieve the lowest possible costs. NASA competitively selected the Mars 2020 investigations payload.

## Major Contracts/Awards

NASA released an NRA for approximately 25 participating scientists to conduct investigations on the Curiosity rover mission and participate in the tactical and strategic planning of rover science operations. NASA will announce selections in February 2016.

# MARS ROVER 2020

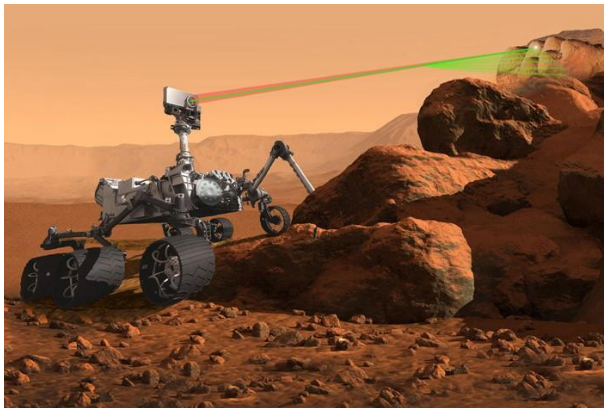
| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Total Budget | 103.6 | -- | 377.5 | 409.0 | 381.0 | 322.0 | 140.0 |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**Mars 2020 will re-use the basic engineering of NASA's Mars Science Laboratory to send a different rover to Mars, with new objectives and instruments, launching in 2020. The rover will carry seven instruments to conduct its science and exploration technology investigations including two contributed by international partners and one to demonstrate a critical technology for future human exploration.**

## PROJECT PURPOSE

The Mars 2020 science rover is a mission, currently in formulation, that will advance the scientific priorities detailed in the National Research Council's Planetary Science Decadal Survey, entitled "Vision and Voyages for Planetary Science in the Decade 2013-2022." In addition, the mission provides an opportunity for payload elements provided by the HEOMD and the Space Technology Mission Directorate (STMD) that align with their priorities and compatible with SMD priorities. The Mars 2020 mission is the essential next step in an evolving program of Mars exploration that will ultimately involve human exploration.

NASA's Mars 2020 mission will build upon many discoveries from the Mars Curiosity rover and the two Mars Exploration Rovers, Spirit and Opportunity, by taking the next key steps in our understanding of Mars' potential as a habitat for past or present life. The Mars 2020 rover will seek signs of past life on Mars, collect and store a set of samples for potential return to Earth in the future, and test new technology to benefit future robotic and human exploration of Mars

## EXPLANATION OF MAJOR CHANGES IN FY 2017

NASA increased the Mars 2020 budget to ensure coverage of the KDP-B cost range.

# MARS ROVER 2020

| Formulation | Development | Operations |
| --- | --- | --- |

## PROJECT PRELIMINARY PARAMETERS

The Mars 2020 mission is planned to launch in July 2020, landing on Mars in February 2021, and spending at least one Mars year (two Earth years) exploring the landing site region. The mission uses much of the design of the highly successful MSL/Curiosity rover, which has been exploring Mars since 2012. The Mars 2020 rover body and other major hardware (such as the cruise stage, aeroshell, and heat shield) would be near-duplicates of the systems of MSL and will take maximum advantage of engineering heritage. The new rover will carry more sophisticated, upgraded hardware and new instruments to conduct geological assessments of the rover's landing site, determine the potential habitability of the environment, and directly search for signs of ancient Martian life. To minimize costs and risks, NASA will use a proven landing system and rover chassis design as much as possible, while still delivering a highly capable rover.

The Mars 2020 rover is carrying a competitively selected science and technology instrument payload of seven instruments. NASA chose five of those instruments to provide the clearest possible measurements for seeking possible signs of ancient life (potential “biosignatures”) on Mars over its long, 4.6 billion-year history. NASA chose the remaining two instruments to assess environmental hazards and resources for future human exploration. The rover also will collect and store samples of rocks and soils in sealed tubes, which will be stored on the surface of Mars for possible return to Earth by a subsequent mission.

The rover’s baseline power source is a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) provided by the U.S. Department of Energy. It uses the heat from the natural decay of plutonium-238 to generate electricity. NASA and ESA telecommunications relay assets in Mars orbit will support the mission.

## ACHIEVEMENTS IN FY 2015

The Mars 2020 mission formally entered Phase B of formulation in May 2015.

## WORK IN PROGRESS IN FY 2016

The Mars 2020 mission will complete Phase B/formulation with the Preliminary Design Review (PDR) and confirmation review process and begin Phase C/implementation.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

The Mars 2020 mission will complete the Critical Design Review (CDR) in preparation to begin Phase D of Implementation.

# MARS ROVER 2020

| Formulation | Development | Operations |
|---|---|---|

## ESTIMATED PROJECT SCHEDULE

| Milestone | Formulation Authorization Document | FY 2017 PB Request |
|---|---|---|
| Formulation Authorization | Oct 23, 2013 | N/A |
| KDP-A | Nov 12, 2013 | N/A |
| KDP-B | May 20, 2015 | N/A |
| KDP-C | Mar 2016 | Mar 2016 |
| KDP-D | Dec 2017 | Dec 2017 |
| Launch | Jul/Aug 2020 | Jul/Aug 2020 |

## Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review.

| KDP-B Date | Estimated Life Cycle Cost Range ($M) | Key Milestone | Key Milestone Estimated Date Range |
|---|---|---|---|
| May 20, 2015 | 2,186-2,351 | Launch | July 2020 |

## Project Management & Commitments

JPL will manage Mars 2020 and will provide systems engineering, safety and mission assurance, project scientists, flight dynamics, payload management, and mission system management.

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| Spacecraft | Similar in design to the MSL flown and landed successfully in 2012 | Provider: JPL<br>Lead Center: JPL<br>Performing Center(s): JPL<br>Cost Share Partner(s): N/A | N/A |

# MARS ROVER 2020

| Formulation | Development | Operations |
|---|---|---|

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| Mastcam-Z | Advanced camera system with panoramic and stereoscopic imaging capability with the ability to zoom | Provider: Arizona State University<br>Lead Center: JPL<br>Performing Center(s): N/A<br>Cost Share Partner(s): N/A | Competitive selection on Jul 31, 2014 |
| SuperCam | Instrument that can provide imaging, chemical composition analysis, and mineralogy | Provider: Los Alamos National Laboratory<br>Lead Center: JPL<br>Performing Center(s): N/A<br>Cost Share Partner(s): Centre National d'Etudes Spatiales | Competitive selection on Jul 31, 2014 |
| PIXL | An X-ray fluorescence spectrometer that will also contain an imager with high resolution to determine the fine scale elemental composition of Martian surface materials | Provider: JPL<br>Lead Center: JPL<br>Performing Center(s): N/A<br>Cost Share Partner(s): N/A | Competitive selection on Jul 31, 2014 |
| SHERLOC | A spectrometer that will provide fine-scale imaging and uses an ultraviolet (UV) laser to determine fine-scale mineralogy and detect organic compounds. | Provider: JPL<br>Lead Center: JPL<br>Performing Center(s): N/A<br>Cost Share Partner(s): N/A | Competitive selection on Jul 31, 2014 |
| RIMFAX | A ground-penetrating radar that will provide centimeter-scale resolution of the geologic structure of the subsurface | Provider: Norwegian Defence Research Establishment, Norway<br>Lead Center: JPL<br>Performing Center(s): N/A<br>Cost Share Partner(s): NASA SMD | Competitive selection on Jul 31, 2014 |
| MEDA | A set of sensors that will provide measurements of temperature, wind speed and direction, pressure, relative humidity and dust size and shape | Provider: Centro de Astrobiologia, Instituto Nacional de Tecnica Aeroespacial, Spain<br>Lead Center: JPL<br>Performing Center(s): N/A<br>Cost Share Partner(s): NASA HEOMD/STMD | Competitive selection on Jul 31, 2014 |

# MARS ROVER 2020

| Formulation | Development | Operations |
|---|---|---|

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| MOXIE | An exploration technology investigation that will produce oxygen from Martian atmospheric carbon dioxide | Provider: Massachusetts Institute of Technology<br>Lead Center: JPL<br>Performing Center(s): JPL<br>Cost Share Partner(s): HEOMD/STMD | Competitive selection on Jul 31, 2014 |

## Project Risks

| Risk Statement | Mitigation |
|---|---|
| If: Planetary Protection/Contamination Control (PP/CC) requirements or risk reduction measures result in modifications to the PP/CC architecture and design approach,<br>Then: Cost growth and schedule delays could be incurred, as well as impacts to the design of other parts of the Rover. | Held JPL institutional and Mars Program sponsored reviews in September and October 2015, respectively, to vet PP/CC approach with other stakeholders. Actively reviewing draft Planetary Protection Plan with stakeholders to ensure timely feedback prior to PDR. |
| If: Landing site requirements and/or surface operability considerations for Mars 2020 result in the need to add Terrain Relative Navigation (TRN) to ensure sufficiently high probability of a successful landing near science targets,<br>Then: Lander vision system and associated cost will be baselined, which may require that other elements of the mission be descoped. | Project is holding technical resources to support TRN and is coordinating with ongoing technology development task.<br>Project is executing risk reduction activities to ensure they can execute TRN with acceptable technical and implementation risk should it be baselined. The project has also assessed the benefit of TRN for the top landing site candidates<br>The Project has developed implementation and accommodation plans, and reviewed them at the TRN PDR in November 2015. |
| If: One or several of the aggregated EDL residual risks or unknown-unknowns that are inherited from MSL is realized (such as single point failures, environmental factors),<br>Then: Could cause loss of mission. | Risk updated to remove risks retired by MSL's flight itself and Mars 2020 plans that will correct some testing shortfalls. Previously 43 identified risks; reduced to 27.<br>Reexamine aggregated risks to understand if any baseline changes affect them. It is very likely that the Mars 2020 mission will need to accept most, if not all, of the aggregated residual risks.<br>As part of flight software scrub, identify any other residual accepted risks from MSL than can be mitigated. |

# MARS ROVER 2020

| Formulation | Development | Operations |
| --- | --- | --- |

## Acquisition Strategy

NASA is acquiring the spacecraft and flight systems for the Mars 2020 mission through JPL and the radioisotope power system through the Department of Energy, taking advantage of the previous investment in the MSL project to maximize heritage. By using contracts existing from the MSL project to procure new versions of the as-flown hardware, JPL plans to maintain the lowest possible costs. NASA competitively selected the Mars 2020 investigations payload.

### MAJOR CONTRACTS/AWARDS

NASA released an announcement of opportunity for the Mars 2020 rover instruments on September 24, 2013, with selections announced on July 31, 2014. NASA selected seven science instruments and exploration technology investigations for the Mars Rover 2020 payload.

| Element | Vendor | Location (of work performance) |
| --- | --- | --- |
| Aeroshell | Lockheed Martin | Denver, CO |
| Actuators | Cobham | Hauppauge, NY |
| Robotic arm | Motiv | Pasadena, CA |

### INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
| --- | --- | --- | --- | --- | --- |
| Life Cycle | SRB | Mar 12, 2015 | System Requirements Review (SRR)/ Mission Definition Review (MDR) | Completed | PDR |
| Life Cycle | SRB | Feb 2016 | PDR | TBD | CDR |
| Life Cycle | SRB | Nov 2016 | CDR | TBD | SIR |
| Life Cycle | SRB | Nov 2017 | System Integration Review (SIR) | TBD | ORR |
| Life Cycle | SRB | May 2020 | Operations Readiness Review (ORR) | TBD | N/A |

# OTHER MISSIONS AND DATA ANALYSIS

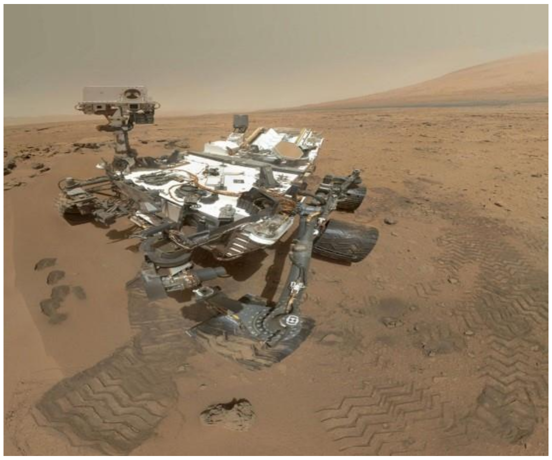
## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Mars Organic Molecule Analyzer (MOMA) | 24.5 | -- | **6.8** | 5.2 | 4.6 | 3.0 | 1.5 |
| Aeroscience Ground Test Capabilities | 0.0 | -- | **14.6** | 15.5 | 21.5 | 22.2 | 22.2 |
| ExoMars | 1.5 | -- | **1.4** | 1.4 | 1.5 | 1.5 | 1.5 |
| Mars Program Management | 23.5 | -- | **19.9** | 19.7 | 19.8 | 18.9 | 10.8 |
| Mars Future Missions | 0.0 | -- | **10.0** | 12.0 | 12.0 | 12.0 | 12.0 |
| Mars Mission Operations | 1.5 | -- | **1.9** | 1.9 | 1.9 | 1.9 | 1.9 |
| Mars Research and Analysis | 10.0 | -- | **9.3** | 9.6 | 9.7 | 9.7 | 9.7 |
| Mars Technology | 7.0 | -- | **0.5** | 2.6 | 17.1 | 61.3 | 34.4 |
| 2011 Mars Science Lab | 63.5 | -- | **58.0** | 58.0 | 48.0 | 0.0 | 0.0 |
| Mars Reconnaissance Orbiter 2005 (MRO) | 27.9 | -- | **27.9** | 27.9 | 27.9 | 27.9 | 27.9 |
| Mars Exploration Rover 2003 | 13.7 | -- | **13.7** | 0.0 | 0.0 | 0.0 | 0.0 |
| Mars Odyssey 2001 | 12.0 | -- | **12.7** | 0.0 | 0.0 | 0.0 | 0.0 |
| Mars Express | 2.5 | -- | **2.6** | 0.0 | 0.0 | 0.0 | 0.0 |
| Mars Atmosphere & Volatile EvolutioN | 13.8 | -- | **28.0** | 26.0 | 20.0 | 18.0 | 18.0 |
| **Total Budget** | **201.4** | **--** | **207.3** | **179.8** | **184.0** | **176.4** | **139.9** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

# OTHER MISSIONS AND DATA ANALYSIS



**All of our future missions will be driven by rigorous scientific questions that will continuously evolve as we make new discoveries. Brand new technologies will enable us to explore Mars in ways we never have before, resulting in higher-resolution images, precision landings, and longer-ranging surface mobility.**

Other Missions and Data Analysis includes the NASA contribution to the European Space Agency ExoMars 2018 rover, the operating Mars missions, Mars Research and Analysis, Mars Technology, and Mars Program Management. Also included are the NASA-contributed Electra communications radios that NASA delivered to the European Space Agency to fly on their 2016 ExoMars Trace Gas Orbiter.

## Mission Planning and Other Projects

### MARS ORGANIC MOLECULE ANALYZER (MOMA)

MOMA is the core astrobiology instrument on the ESA ExoMars 2018 rover, and it addresses the top ExoMars science goal of seeking signs of past or present life on Mars. The MOMA-MS is the NASA-provided subsystem of MOMA, which is in development. It is composed of a dual-source mass spectrometer, including laser desorption capability, to detect a wide range of organic molecules in Martian samples. Organic structure and distribution can be indicators of past or present life.

### AEROSCIENCE GROUND TEST CAPABILITIES

NASA has established a new Aeroscience Ground Test Capabilities project to sustain Mars entry, descent, and landing test capabilities. This project provides the base funding to maintain capabilities, to ensure they are available when needed for specific missions.

### EXOMARS

The ESA Exobiology on Mars (ExoMars) program is a series of missions designed to understand if life ever existed on Mars. The first mission in the ExoMars program is the 2016 Trace Gas Orbiter (TGO). For this mission, NASA contributed two Electra telecommunication radios, identical to those used successfully on NASA's Mars Reconnaissance Orbiter and MAVEN. Electra acts as a communications relay and navigation aid for Mars spacecraft. Electra's ultra-high frequency (UHF) radios support navigation, command, and data-return needs.

### MARS PROGRAM MANAGEMENT

Mars Program Management provides for the broad-based implementation and programmatic management of the Mars Exploration program. Mars Program Management also supports independent panel reviews, studies regarding planetary protection, advanced mission studies and program architecture, program science, and telecommunications coordination and integration.

## MARS MISSION OPERATIONS

Mars Mission Operations provides management and leadership for the development and operation of Mars multi-mission systems for operations. Mars Mission Operations supports and provides common operational systems and capabilities at a lower cost and risk than having each Mars project produce systems individually.

## MARS RESEARCH AND ANALYSIS

Mars R&A provides funding for research and analysis of Mars mission data in order to understand how geologic, climatic, and other processes have worked to shape Mars and its environment over time, as well as how they interact today. Specific investments include:

Mars Data Analysis, which analyzes archived data collected on Mars missions; and

Critical Data Products, which provides data for the safe arrival, aero-maneuver, entry, descent, and landing at Mars.

Data analysis through Mars R&A allows a much broader and objective analysis of the data and samples. It also allows research to continue for many years after the mission completion. These research projects increase our scientific understanding of Mars' geology and environment, disseminating the results through the scientific publications. Works in Critical Data Products identified potential hazards and landing sites for future missions, and provided an opportunity to analyze data from Comet Siding Spring, which passed close to Mars in October of 2014. Researchers make fundamental measurements and discoveries and testable hypotheses about the Martian environment through these programs.

### Recent Achievements

The finding that a primitive ocean on Mars held more water than Earth's Arctic Ocean, was deduced from the data collected from ground-based observatories (the Very Large Telescope, Keck, and InfraRed Telescope Facility) to measure the heavy and light isotopes of water in the Red Planet's atmosphere.

## MARS TECHNOLOGY

Mars Technology focuses on technological investments that lay the groundwork for successful future Mars missions, such as sample handling and processing technologies; entry, descent, and landing capabilities; Mars ascent vehicle component technology, and surface-to-orbit communications improvements.

### Recent Achievements

In FY 2015, the Mars Technology Development program matured technologies to enable and improve future landed missions on Mars. The Safe and Precise EDL task was completed and prepared for infusion into the Mars 2020 project. The Safe Rover Mobility task concluded with a successful demonstration of advanced mobility capabilities in the Mars Yard, and the technology is available for transfer to the Mars 2020 project. The MAV and Containment Assurance Fundamental Focused Technology tasks are continuing, with a planned conclusion in early FY 2016.

## Operating Missions

### 2011 MARS SCIENCE LAB

MSL and its Curiosity rover, which successfully landed in August 2012, has completed its prime mission exploration activities. The Curiosity rover is exploring and quantitatively assessing regions on Mars as potential past habitats for life, and has determined that Mars, at least at one point in time, was once able to support microbial life. Curiosity is twice as long and three times as heavy as the Mars Exploration Rover Opportunity. The Curiosity rover is collecting Martian soil and rock samples and analyzing them for organic compounds and environmental conditions that could have supported microbial life, and making measurements of the Martian atmosphere, the radiation environment, and the weather. MSL is the first planetary mission to use precision landing techniques, steering itself toward the Martian surface. This landing method enabled the rover to land in an area less than 12 miles in diameter, about one-sixth the size of previous landing zones on Mars, and this successful system is the basis of the system architecture of the Mars 2020 mission. In addition, Curiosity is the first planetary rover to make use of a nuclear power source, which gave the rover the ability to travel up to 12 miles during the two-year primary mission. This international partnership mission uses components provided by the space agencies of Russia, Spain, and Canada.

#### Recent Achievements

Curiosity has traveled over 7 miles and has been exploring the lower reaches of Mt. Sharp – the prime science target of the mission. It is during the trek to Mt. Sharp that the on-board laboratory measured plumes of methane ten times above the background level – this presents a challenge in our understanding of the Martian atmosphere because scientists cannot adequately explain the source or the sink for the methane. In addition, Curiosity has measured the fixed nitrogen, permitting a primitive nitrogen cycle and making nitrogen biologically accessible, critical for potential Martian life. At the base of Mt. Sharp, the rover has been able to sample several sediment types as it moves from the plains of Gale Crater to up the initial slope of Mt. Sharp. One derived conclusion is that a combination of lake and river deposits formed the base of Mt. Sharp and indicates that early Mars had an environment with an active hydrologic cycle that could support a substantial body of water for extended periods. Mineral-filled veins in the studied lake-deposits can be attributed to multiple generations of water at the surface, again indicative of an environment more conducive to life.

### MARS RECONNAISSANCE ORBITER 2005 (MRO)

MRO, currently in its third extended operations phase, carries HiRISE, the most powerful camera ever flown on a planetary exploration mission. This capability provides a more detailed view of the geology and structure of Mars, and helps identify obstacles that could jeopardize the safety of future landers and rovers. MRO also carries a sounder to find subsurface water, an important consideration in selecting scientifically worthy landing sites for future exploration. Other science instruments on this spacecraft identify surface minerals and study how the Martian atmosphere transports dust and water. A second camera acquires medium-resolution images that provide a broader geological and meteorological context for more detailed observations from higher-resolution instruments. In addition, MRO carries a high resolution imaging spectrometer, CRISM, which can map minerals at unprecedented spatial resolution. MRO will follow up on recent discoveries to determine the extent of ancient aqueous environments, reveal the three dimensional structure and content of the polar ice deposits, characterize the episodic nature of great dust storms, and detect seasonal flows of liquid water on Mars today.

MRO is capturing unique views of Mars, including continuing discoveries of warm-season flows of salty water. The camera also identified and characterized the landing site for the Curiosity rover. MRO will also identify landing sites for future landers in 2018, 2020, and potential human missions. MRO also serves as a major installment of an “interplanetary Internet,” a crucial service for future spacecraft to communicate back to Earth.

### Recent Achievements

MRO has been key in identifying mineral and morphological features from orbit that guide the robotic missions – flagging the large clay deposits in Marathon Valley for Opportunity to explore. HiRISE has guided the Curiosity rover by highlighting terrain that could be a hazard to the rover wheels and has connected a major geological unit to the base of Mt. Sharp. MRO has helped landed missions to the extent of finding the Beagle 2 Mars Lander, which has been thought lost since 2003, showing it survived the landing sufficiently to partially deploy the solar arrays.

The Orbiter witnessed the Comet Siding Spring fly-by and detected dust from the comet that impacted Mars and vaporized high in the atmosphere, producing debris, which resulted in significant temporary changes to the planet's upper atmosphere. The Shallow Subsurface Radar (SHARAD) also detected the enhanced ionosphere and scientists determined that the electron density of the ionosphere on the planet's night side was five to 10 times higher than usual. Studies of the comet itself, made with MRO's HiRISE, revealed the nucleus is smaller than the expected 1.2 miles and a rotation period for the nucleus of eight hours.

Recurring Slope Lineae (RSL) are seasonal dark streaks that scientists have described as possibly related to liquid water. The new findings based on CRISM measurements, show hydrated salts (perchlorates) on the slopes, which would lower the freezing point of a liquid brine to enable a flow at sub-freezing temperatures. These observations provide a mechanism for flow features on the slopes of Mars and have now doubled the number of proven sites where perchlorates exist on the Martian surface.

## MARS EXPLORATION ROVER 2003

For over 11 years, the Mars Exploration Rover Opportunity has explored geological settings on the surface of Mars. It has expanded understanding of the history and the geological processes that shaped Mars, particularly those involving water. Opportunity has trekked for 25 miles across the Martian surface, (recently breaking the distance record for traverse on a planetary body beyond Earth), conducting field geology, making atmospheric observations, finding evidence of ancient Martian environments where intermittently wet and habitable conditions existed, and sending back to Earth well over 200,000 spectacular, high-resolution images. The budget includes mandatory funding to continue Opportunity operations in FY 2017.

# OTHER MISSIONS AND DATA ANALYSIS

### Recent Achievements

In March of 2015, the Mars Exploration Rover Opportunity completed its first Red Planet marathon -- 26.219 miles (42.195 kilometers) - with a finish time of roughly 11 years and two months.

Opportunity has entered Marathon Valley has begun an extensive campaign exploring the clays identified by MRO's CRISM in orbit. The rover will concentrate on the south facing slopes of the valley to maximize the solar panel exposure to boost power and survive its seventh Martian winter.

## MARS ODYSSEY 2001

Mars Odyssey, currently in its sixth extended mission operations phase, is still in orbit around Mars. It continues to send information to Earth about Martian geology, climate, and mineralogy. Measurements by Odyssey enabled scientists to create maps of minerals and chemical elements and identify regions with buried water ice. Images that measure the surface temperature provided spectacular views of Martian topography. Mars Odyssey will continue critical long-term longitudinal studies of the Martian climate. Odyssey has served as the primary means of communications for NASA Mars surface explorers over the past decade, and continues that role for the Opportunity and Curiosity rovers. The budget includes mandatory funding to continue Mars Odyssey operations in FY 2017.

### Recent Achievements

A new analysis by Odyssey's Thermal Emission Spectrometer, along with MRO's CRISM, of the largest known deposit of carbonate minerals on Mars suggests that the original Martian atmosphere may have already lost most of its carbon dioxide by the era of valley network formation. Carbonate forms from carbon dioxide in the atmosphere, but it seems there is not nearly enough carbonate to account for the lost atmosphere.

In November 2015, NASA's Mars Odyssey spacecraft initiated a change in its orbit to early morning to enable the first systematic observations of how morning fogs, clouds, and surface frost develop in different seasons on the Red Planet.

## MARS EXPRESS

Mars Express, currently in its third extended mission operations phase, is an ESA mission that provides an understanding of Mars as a "coupled" system: from the ionosphere and atmosphere down to the surface and sub-surface. This mission addresses the climatic and geological evolution of Mars as well as the potential for life on the planet. NASA contributed components for the Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) and Analyzer of Space Plasmas and Energetic Atoms (ASPERA) instruments aboard Mars Express, and participates in the scientific analysis of mission data. The budget includes mandatory funding to continue the U.S. contribution to Mars Express in FY 2017.

## MARS ATMOSPHERE AND VOLATILE EVOLUTION (MAVEN)

MAVEN, successfully launched in 2013, will provide a comprehensive picture of the Mars upper atmosphere, ionosphere, solar energetic drivers, and atmospheric losses, to determine how the Mars atmosphere evolved through time. The mission will help answer long-standing questions regarding the loss of the Mars atmosphere, climate history, liquid water, and habitability. MAVEN will provide the first direct measurements ever taken to address key scientific questions about Mars' evolution. The MAVEN mission is the second mission of NASA's Mars Scout program. It will explore the upper atmosphere, ionosphere, and interactions with the Sun and solar wind. Scientists will use MAVEN data to determine the role that loss of volatile compounds (such as carbon dioxide and water) from the Mars atmosphere to space has played through time, giving insight into the history of Mars' atmosphere and climate, liquid water, and planetary habitability. As with all Mars Exploration Program orbiters, MAVEN also carries an Electra radio for communications with rovers and landers on the Mars surface. MAVEN will provide contingency relay support during its primary science mission and eventually evolve into a more regular communications role.

### Recent Achievements

MAVEN spacecraft has detected metal ions near the ionospheric peak at 130km. This is the first actual detection of a long-lived layer of metal ions at Mars. The metallic layer is likely due to the ablation of incoming micrometeoroids into the atmosphere. MAVEN obtained an ultraviolet image of the hydrogen surrounding Comet Siding Spring and the results probe the size and properties of the comet's nucleus and the properties of dust and gas in the comet's coma. Comet material blanketed most of the northern hemisphere of Mars, scattering sunlight by atomic hydrogen.

MAVEN observed an unexplained high-altitude dust cloud around Mars from about 93 miles to 190 miles above the surface. Possible sources for the observed dust include dust wafted up from the atmosphere; dust coming from Phobos and Deimos, the two moons of Mars; dust moving in the solar wind away from the Sun; or debris from comets and asteroids. However, no known process on Mars can explain the appearance of this dust in the observed locations from any of these sources.

For five days just before Christmas 2014, MAVEN's Imaging Ultraviolet Spectrograph (IUVS) saw a bright ultraviolet auroral glow spanning Mars' northern hemisphere. The source of the energetic particles appears to be the Sun. MAVEN's Solar Energetic Particle instrument detected a huge surge in energetic electrons just before the onset of the aurora. In retrospect, it is not surprising that Mars would have a diffuse aurora, similar to Earth's, except not confined to polar regions by a global magnetic field because Mars lost its magnetic field billions of years ago.

# OUTER PLANETS AND OCEAN WORLDS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| JUICE - Jupiter Icy Moons Explorer | 7.4 | -- | **20.5** | 17.4 | 4.1 | 2.0 | 2.3 |
| Jupiter Europa | 100.0 | 175.0 | **49.6** | 24.2 | 65.2 | 117.5 | 236.5 |
| Outer Planets Research | 8.5 | -- | **8.5** | 8.5 | 8.5 | 8.5 | 8.5 |
| Cassini | 68.1 | -- | **58.7** | 5.9 | 0.0 | 0.0 | 0.0 |
| **Total Budget** | **184.0** | **--** | **137.3** | **56.0** | **77.8** | **128.0** | **247.3** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

**Europa, with its probable vast subsurface ocean sandwiched between a potentially active silicate interior and a highly dynamic surface ice shell, offers one of the most promising extraterrestrial habitable environments, and a plausible model for habitable environments beyond our solar system - Vision and Voyages for Planetary Science in the Decade 2013-2022**

The Outer Planets and Ocean Worlds program enables science investigations of the outer solar system with a special emphasis on the exploration of worlds in our solar system possessing vast expanses of liquids, just as Earth does. These liquid reservoirs, most notably those composed of liquid water, provide insight into some of the most fundamental questions about life and the evolution of the solar system. The exploration of ocean worlds has the highest relevance and potential in the search for extant life and its habitable environments beyond Earth, one of NASA's strategic objectives.

NASA missions have revealed an increasing number of ocean worlds in our solar system while at the same time providing enticing though limited details about these unexpected oceans. Not far underneath its icy crust, Europa contains a global liquid water ocean twice as large as Earth's oceans. Recently, scientists detected a similar though smaller global ocean on Enceladus, a small moon orbiting Saturn. Other moons (such as Ganymede, Callisto, and Titan) have been shown to possess perched oceans deep beneath their surfaces, and Titan has also been shown to possess huge lakes of liquid methane on its surface – the only place beyond Earth with lakes exposed to an atmosphere.

Simultaneously with these discoveries, astrobiology research along with the exploration of Earth's oceans have demonstrated the pervasiveness of life given the proper conditions and environment. Research has increasingly indicated that ocean worlds possess at least some of the conditions necessary for extant life: long-lived oceans providing liquid water and a stable habitat, hydrothermal activity providing energy, and organics providing the necessary materials, among others. Thus, ocean worlds are the most likely places to search for currently habitable environments in the solar system and the life forms that could exist in those environments. The Outer Planets and Ocean Worlds program enables science investigations spanning the diversity of worlds hosting large liquid bodies in the outer solar system.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Mandatory Budget Authority** | -- | -- | 33 | -- | -- | -- | -- |

In FY 2017 the Outer Planets and Ocean Worlds program will develop a technology roadmap and initiate a strategic set of investments.

Outer Planets and Ocean Worlds is supported in part with mandatory funding (see table, above). The mandatory investment includes $33 million for the Jupiter Europa mission.

## ACHIEVEMENTS IN FY 2015

During FY 2015, NASA selected the science payload for the Europa multiple flyby mission. This significant milestone provided nine instruments and associated science teams that will lead the exploration of one of the most promising ocean worlds for the possible detection of life beyond Earth. The Europa mission expects to provide more than 90% of the science return of the original Europa Orbiter mission concept endorsed by the Planetary Decadal Survey, but at half the cost of that earlier mission concept with this scientific payload.

The Cassini mission completed a set of orbits at high inclination around Saturn that allowed the spacecraft to observe the rings and poles of the planet from an improved vantage point. The spacecraft returned to a more equatorial orbit that allowed flybys of Saturn's moons to resume. The spacecraft completed an additional eight flybys of Titan, bringing the total to 113, as well as the final two flybys of the small icy satellite Dione. During FY 2015 the Cassini science team made three significant discoveries about Enceladus, the tiny icy moon ejecting plumes of water into space from its ocean below its surface: the team confirmed the presence of a global liquid water ocean, detected signs of methane (an organic molecule with potential biological importance) in the plume, and derived evidence suggesting hydrothermal activity in the ocean. These discoveries confirmed Enceladus' place as an ocean world in our solar system that may harbor life today.

## WORK IN PROGRESS IN FY 2016

The Europa mission will continue to integrate and accommodate the selected science instruments into the spacecraft design in FY 2016. This task is proceeding on schedule without any significant issues. Phase A concept development activities will conclude in late FY 2016. The Cassini mission will conduct an additional ten flybys of Titan and the final three flybys of Enceladus, and will complete final preparations for the last proximal orbits near Saturn prior to impact with the planet in FY 2017.

# OUTER PLANETS AND OCEAN WORLDS

The Outer Planets and Ocean Worlds program will begin detailed definition of the technologies needed for ocean world exploration, and construct an acquisition strategy for implementation in FY 2017.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

In FY 2017, the Outer Planets and Ocean Worlds program will identify a strategic set of investments with three goals: safely landing on hazardous icy surfaces, directly accessing oceans, and accurately detecting biosignatures and extant life. Development of these technologies will enable missions to ocean worlds of any size and class that are able to address the two key scientific questions of the habitability of the oceans and the presence of life. By collaborating with the Astrobiology program, existing programs investing in relevant instrument development and studies of analog environments on Earth (such as buried subglacial lakes in Antarctica) will be targeted to advance similar goals shared by both the Outer Planets and Ocean Worlds and Astrobiology programs. External partnerships with NOAA and the NSF will bring the expertise of the Earth oceanography community to bear on the challenges facing NASA and allow NASA to field test the resulting technologies on Earth, helping to advance terrestrial studies on the home planet before exploring the ocean worlds beyond.

The Europa multiple flyby mission will advance from Phase A (concept development) to Phase B (preliminary design) during early FY 2017. This flagship-class mission will be the first NASA mission explicitly designed to explore an ocean world.

At the end of FY 2017, the Cassini spacecraft with its nearly depleted fuel tanks will intentionally impact Saturn, concluding 13 years of exploration of the Saturn system. Already one of NASA's most successful and productive missions, during its final year Cassini will conduct a series of daring orbits, skimming Saturn's clouds as it dives between Saturn and the inner edge of its rings. The scientific return of this grand finale will be unique and answer questions about Saturn's internal structure and the dynamics and mass of the rings. Until then Cassini will conduct additional flybys of the ocean world Titan, investigating its methane lakes and methane-based "water" cycle.

# Mission Planning and Other Projects

## JUPITER ICY MOONS EXPLORER (JUICE)

NASA is collaborating with ESA on this ESA-led mission to Ganymede and the Jupiter system. The JUICE mission provides an opportunity for comparative investigation of three of the ocean worlds in the Jupiter system: Europa, Ganymede, and Callisto. Researchers believe Ganymede and Callisto possess liquid water oceans sandwiched between ice layers deep beneath their surfaces. ESA plans to launch the mission in 2022 for arrival at Jupiter in 2030. It has a tentative model payload of 11 scientific instruments. The NASA contribution consists of three separate projects: one full instrument, Ultra Violet Spectrometer; two sensors for the Particle Environment Package suite of instruments; and the transmitter and receiver hardware for the Radar for Icy Moon Exploration instrument.

# OUTER PLANETS AND OCEAN WORLDS

## JUPITER EUROPA

Jupiter's moon Europa has the largest known ocean in the solar system, and is one of the most likely places to find current life beyond our Earth. For over 15 years NASA has developed concepts to explore Europa and determine if it is habitable based on characteristics of its vast oceans (twice the size of all of Earth's oceans combined), the ice surface – ocean interface, the chemical composition of the intriguing, irregular brown surface areas, and the current geologic activity providing energy to the system. After thorough investigation of concept options, NASA has initiated the Phase A study of a multiple flyby mission that delivers the most science for the least cost and risk of all the concepts studied. The flyby concept can take advantage of solar power and requires no new technology development, despite the harsh radiation environment that the spacecraft will encounter during the flybys.

NASA established a Europa project in FY 2015, initiating the formulation phase, and competitively selected nine instruments for development. In FY 2016, the project is formulating requirements, architecture, planetary protection requirements, risk identification and mitigation plans, cost and schedule range estimates, and payload accommodation for a mission to Europa. In FY 2017, the project will be ready to enter its preliminary design phase.

Costs and schedule for the current Europa mission design are not firm, as the mission is still in formulation and NASA does not commit to costs and schedules until KDP-C. The notional outyear profile in the Budget may support a launch as early as the late 2020s, assuming the mission concept and scope remain stable.

Per Public Law 114-113, Division B, Title III, the following table provides rough estimates for the current mission design, assuming launch in 2022. Acceleration of the launch to 2022 is not recommended, given potential impacts to the rest of the Science portfolio. The Administration continues to support a balanced science program, as recommended in the Decadal Survey.

| | FY17 | FY18 | FY19 | FY20 | FY21 |
|---|---|---|---|---|---|
| **Europa 2022 ($M)** | 194.0 | 272.0 | 456.0 | 678.0 | 482.0 |

Note: The Europa profile above assumes an Evolved Expendable Launch Vehicle, as the cost of an SLS flight is not yet known.

In FY 2016, NASA will assess the potential for secondary payloads that may enhance science return from the mission. Given the potential for a secondary payload to add cost and complexity to the mission, NASA would have to determine whether such an addition would be feasible from both a technical and budget standpoint. In particular, the limited current knowledge about the Europa surface conditions adds tremendous complexity and technical challenge to successfully landing on the surface.

## OUTER PLANETS RESEARCH

Outer Planets Research increases the scientific return of current and past NASA outer planets missions, guides current mission operations (e.g., selecting Cassini imaging targets), and paves the way for future missions (e.g., refining landing sites on Titan, reconsidering the ice shell thickness on Europa).

# OUTER PLANETS AND OCEAN WORLDS

## Operating Missions

### CASSINI

Cassini, in its extended operations phase, is a flagship mission in orbit around Saturn that altered our understanding of the planet, its famous rings, magnetosphere, icy satellites, and particularly the moons Titan and Enceladus. Cassini completed its prime mission in July 2008, completed its Equinox extended mission in July 2010, and began the Solstice extended mission in October 2010. It is exploring the Saturn system in detail, including its rings and moons. A major focus is on the ocean worlds in the Saturn system, Titan (Saturn's largest moon), with its dense atmosphere, methane-based meteorology, and geologically active surface; and Enceladus, a tiny icy body with its unexpected global ocean and steady plumes ejecting water from the South Pole. The Solstice mission is observing seasonal and temporal change in the Saturn system, especially at Titan, to understand underlying processes and prepare for future missions. In FY 2017, an encounter with Titan will change its orbit in such a way that, at closest approach to Saturn, it will be only about 1,800 miles above the planet's cloud tops, and below the inner edge of the D ring. This sequence of approximately 22 "proximal orbits" will provide an opportunity for an entirely different mission for the Cassini spacecraft, investigating science questions never anticipated at the time Cassini launched. The Cassini mission will end after the proximal orbits when a final encounter with Titan will send the Cassini probe into Saturn's atmosphere.

## Program Management & Commitments

Management responsibility for Cassini resides at JPL. Scientific mission priorities for the program and the research efforts reside within SMD's Planetary Science Division.

The Cassini mission is a cooperative project of NASA, the ESA, and the Italian Space Agency.

Cassini is committed to continue delivery of science data until 2018, contingent upon health and status of the spacecraft.

Responsibility for the Europa project resides at JPL, with program management authority assigned to MSFC. Scientific mission priorities for the project and the research efforts reside within SMD's Planetary Science Division.

| Program Element | Provider |
|---|---|
| Outer Planets Research | Provider: HQ<br>Lead Center:<br>Performing Center(s): Multiple<br>Cost Share Partner(s): N/A |
| Cassini | Provider: JPL<br>Lead Center: JPL<br>Performing Center(s): JPL<br>Cost Share Partner(s): The Italian Space Agency provided Cassini's high-gain communication antenna, and ESA built the Huygens probe. |

# OUTER PLANETS AND OCEAN WORLDS

| Program Element | Provider |
|---|---|
| Europa | Provider: JPL<br>Lead Center: JPL<br>Performing Center(s): APL, GSFC, MSFC, JSC, KSC<br>Cost Share Partner(s): N/A |
| JUICE | Provider: JPL (RIME), APL (PEP), SWRI (UVS)<br>Lead Center: MSFC<br>Performing Center(s):<br>Cost Share Partner(s): ESA |

## Acquisition Strategy

Outer Planets Research is included in the annual ROSES NASA Research Announcement. All major acquisitions and contracts for Cassini are in place. NASA has selected the Europa instruments; JPL will determine major system procurements using JPL's internal make/buy decision process.

### INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Europa Systems Require-ment Review & Mission Definition Review | SRB | No earlier than Jun 2016 | Ensure that requirements and concept defined for the project will satisfy mission goals and the concept is complete, feasible, and consistent with available resources. | TBD | No earlier than Mar 2018 |

# TECHNOLOGY

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | 159.2 | -- | 165.5 | 164.4 | 163.5 | 179.7 | 172.0 |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

**Earth-sized Sub-ice Ocean explorer and sampler. The Technology Program is working to miniaturize this technology for Planetary Ocean Worlds exploration.**

Planetary Science missions demand advances in both power and propulsion systems to enable successful trips to harsh environments, trips far from the Sun where the spacecraft cannot be easily solar powered, and missions with highly challenging trajectories and operations. To meet these needs, Planetary Science supports multi-mission capabilities and technology developments in key spacecraft systems, and mission operations. The Planetary Science Technology program includes the Radioisotope Power System (RPS) Program managed by Glenn Research Center, DOE-managed Plutonium production and Production Operations infrastructure, Advanced Technology and Advanced Multi-Mission Operations System (AMMOS) projects.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| (in $ millions) | FY 2015 | FY 2016 | FY 2017 | FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Mandatory Budget Authority** | -- | -- | 10.0 | -- | -- | -- | -- |

Technology is supported in part with mandatory funding (see table, above). The mandatory investment includes $10 million for Advanced Technology, to accelerate technology development related to future power systems and any other areas that are important to future planetary exploration.

# TECHNOLOGY

## ACHIEVEMENTS IN FY 2015

The RPS Program continued to advance the state of technologies for more advanced, higher efficiency power systems to enhance future exploration of deep space. Testing continued on a Stirling engineering unit, providing engineers with a greater understanding of system reliability and lifetime limiting issues. This work will inform technology investment decisions in the future, and retire risk for the development of a future generation of Stirling power systems. The Thermoelectric Technology Development effort is working in partnership with industry to transfer mature Skutterudite thermoelectric technology into a production facility for the potential enhancement of the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG).

## WORK IN PROGRESS IN FY 2016

The RPS Program is investigating the state of Stirling technologies across industry and defining goals and requirements for future Stirling development projects. The RPS Program will complete a Gate Review of the Skutterudite thermoelectric technology transfer effort and develop the plan for the next phase. The Department of Energy (DOE) will complete the first plutonium-238 production demonstration in FY 2016, with the initial production of new Plutonium from the irradiation of Neptunium-237 for shipment to Los Alamos National Laboratory for quality analysis.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

The RPS Program supports Mars 2020 by providing a MMRTG flight unit, and will deliver the MMRTG Qualification Unit in FY 2017 for assembly, test and launch operations. Additionally, RPS will be supporting the New Frontiers Announcement of Opportunity, allowing for a potential mission requirement for MMRTGs or Radioisotope Heater Units. DOE will be performing its second plutonium production demonstration as part of its efforts to restart Plutonium production. LANL will be installing the new plutonium hot press, provided by NASA funding, which will reduce the schedule risk for producing plutonium fuel clad assemblies to future NASA missions.

# Program Elements

## PLUTONIUM

NASA and DOE are implementing a Pu-238 Supply Project to restart domestic production of Plutonium-238 for the first time since the 1980's. NASA funds the effort, which takes place at the DOE's Oak Ridge National Laboratory. An initial production of multiple grams is expected in FY 2016, and as the process is refined and automated over the next several years, it is expected to ramp up to a full operational capability of 1.5 kilograms per year.

## DOE RADIOISOTOPE POWER SYSTEM INFRASTRUCTURE

NASA funds the DOE personnel and infrastructure required to maintain the capability to develop and fuel radioisotope power systems for deep space spacecraft missions. DOE performs the work required for NASA missions at Oak Ridge, Los Alamos, Sandia, and Idaho National Laboratories.

# TECHNOLOGY

## ADVANCED TECHNOLOGY

NASA continues to study future planetary mission requirements to identify needs for technology investment. NASA also engages with stakeholders to ensure the relevance and priorities for existing investments, consistent with the NASA Strategic Technology Investment Plan. NASA will continue investments in advanced energy production and conversion technologies and spacecraft technologies that can uniquely enable future planetary missions, including a future potential enhancement of the Multi-Mission Radioisotope Thermoelectric Generator.

## NUCLEAR RADIOISOTOPE POWER SYSTEMS DEVELOPMENT

The RPS Program is continuing technology development for power conversion for future RPS systems, supporting development and certification of the Multi-Mission RTG for Mars 2020, and overseeing the Plutonium and RPS Infrastructure work done for NASA by the DOE.

# Operating Missions

## ADVANCED MULTI-MISSION OPERATION SYSTEM (AMMOS)

AMMOS provides multi-mission operations, navigation, design, and training tools and services for Planetary Science flight missions, as well as other Science Mission Directorate missions, and invests in improved communications and navigation technologies. The AMMOS project will continue to provide and develop multi-mission software tools for spacecraft navigation, command, control, assessment, and mission planning. In addition, AMMOS will pursue complementary collaborations with the Agency's crosscutting Space Technology program. Utilizing the AMMOS common tools and services lowers individual mission cost and risk by providing a mature base for mission operations systems at significantly reduced development time.

AMMOS also provides support to our international space agency partners, on an as-needed basis. This support typically pertains to navigation assistance and scheduling of NASA's Deep Space Network (DSN) assets.

# Program Management & Commitments

| Program Element | Provider |
|---|---|
| RPS Program | Provider: GRC<br>Lead Center: GRC<br>Performing Center(s): GRC, JPL, GSFC, KSC, DOE<br>Cost Share Partner(s): N/A |

# TECHNOLOGY

| Program Element | Provider |
|---|---|
| Plutonium | Provider: DOE<br>Lead Center: HQ<br>Performing Center(s): GRC, DOE<br>Cost Share Partner(s): N/A |
| DOE Production Operations Infrastructure | Provider: DOE<br>Lead Center: HQ<br>Performing Center(s): GRC, DOE<br>Cost Share Partner(s): N/A |
| AMMOS | Provider: JPL<br>Lead Center: JPL<br>Performing Center(s): JPL, GSFC, JSC, ARC, MSFC, APL<br>Cost Share Partner(s): N/A |

## Acquisition Strategy

DOE provides radioisotope power systems, production operations, and the Plutonium production projects on a reimbursable basis.

# ASTROPHYSICS

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Astrophysics Research | 201.7 | -- | **226.1** | 236.3 | 235.7 | 248.5 | 252.0 |
| Cosmic Origins | 201.0 | -- | **198.5** | 198.4 | 197.3 | 195.5 | 209.5 |
| Physics of the Cosmos | 104.1 | -- | **94.1** | 88.0 | 94.1 | 97.7 | 94.0 |
| Exoplanet Exploration | 100.6 | -- | **133.8** | 148.0 | 309.3 | 373.3 | 450.8 |
| Astrophysics Explorer | 123.3 | -- | **129.0** | 91.0 | 156.0 | 203.5 | 186.2 |
| **Total Budget** | **730.7** | -- | **781.5** | **761.6** | **992.4** | **1118.6** | **1192.5** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

## Astrophysics

# ASTROPHYSICS RESEARCH

**FY 2017 Budget**

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Astrophysics Research and Analysis | 71.1 | -- | **72.7** | 73.0 | 73.0 | 73.0 | 73.0 |
| Balloon Project | 38.0 | -- | **37.0** | 37.3 | 37.4 | 38.9 | 40.4 |
| STEM Education | 42.0 | -- | **25.0** | 25.0 | 25.0 | 25.0 | 25.0 |
| Other Missions and Data Analysis | 50.6 | -- | **91.4** | 101.0 | 100.3 | 111.6 | 113.6 |
| **Total Budget** | **201.7** | **--** | **226.1** | **236.3** | **235.7** | **248.5** | **252.0** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

**Map of the 32-day and night path of the test flight of a super pressure balloon, launched from Wanaka, NZ on March 26, 2015. It maintained a nearly constant altitude of 109,000-110,000 ft.**

The Astrophysics Research program develops innovative technologies for future missions to explore and understand the cosmos, from the nature of planets circling other stars to the birth of distant galaxies and the earliest cosmic history. High-altitude balloon and sounding rocket flights test new types of instruments. These flights also allow a quick response to unexpected events, such as the appearance of a new comet.

The program provides basic research awards for scientists to test their theories, and to understand how they can best use data from NASA missions to gain new knowledge from the cosmos. Awardees analyze the data from Astrophysics missions to understand astronomical events, such as the explosion of a star or the fingerprints of early cosmic history in the microwave background.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Mandatory Budget Authority** | **--** | **--** | **3.0** | **--** | **--** | **--** | **--** |

# ASTROPHYSICS RESEARCH

Astrophysics Research is supported in part with $3 million of mandatory funding for Research and Analysis.

Compared to the FY 2016 Request, this budget request reflects an increase to Science Mission Directorate (SMD) Science, Technology, Engineering, and Mathematics (STEM) activities.

## ACHIEVEMENTS IN FY 2015

NASA launched an Astrophysics experiment on a sounding rocket in 2015 to test new X-ray spectroscopy technology. The Off-plane Grating Rocket for Extended Source Spectroscopy (OGRESS) payload examined the X-rays streaming from the Cygnus Loop, a supernova remnant, to assess the debris from this 20,000-year-old explosion. Flying such technology opens the door to probe the deep universe for missing matter believed, but not proven, to exist.

The Balloon project supported the annual Antarctic long-duration balloon flights, a campaign to New Zealand, and a campaign of conventional flights from Fort Sumner, NM.

The balloon payload Suborbital Polarimeter for Inflation Dust and the Epoch of Reionization (SPIDER), launched from Antarctica, measured the radiation that fills the Milky Way and mapped the tiny fluctuations in the cosmic microwave background that are the seeds of the largest cosmic structures. This payload flew for 15 days. Another payload, one of the largest balloon payloads ever flown, was to detect radio signals from ultra-high energy neutrino interactions in the deep Antarctic ice and extremely high-energy cosmic rays when they penetrate the Earth’s atmosphere. NASA successfully flew this payload in excess of 22 days in Antarctica.

NASA completed reconfiguration of the successful balloon-borne Cosmic Ray Energetics and Mass (CREAM) payload to fly on the International Space Station (ISS). After completing its thermal vacuum tests at the Goddard Space Flight Center (GSFC) in August 2015, NASA shipped the ISS-CREAM payload to the Kennedy Space Center (KSC) to await its planned launch.

Research on exoplanets confirmed the nature of exoplanet candidates identified by the Kepler project, and explored the nature of planets circling other stars.

## WORK IN PROGRESS IN FY 2016

Five research groups plan to launch Astrophysics experiments on sounding rockets in 2016. One experiment is to image the debris disk around the star Epsilon Eridani. Another is dedicated to the study of low energy X-ray emission produced by solar wind charge exchange by measuring the spatial signature of its emission. The third investigation is to determine the fraction of Lyman-alpha emission that escapes from nearby star-forming galaxies and to quantify its relationship with galactic environment. The fourth experiment will measure the ultraviolet light from young stars. The fifth experiment will provide a uniform brightness calibration for stars from infrared to ultraviolet wavelengths, which is required to link data from different space telescopes accurately.

The Balloon project plans to support the annual Antarctic long-duration balloon flights, a campaign to New Zealand, as well as campaign with conventional flights from Palestine, TX and Fort Sumner, NM. NASA will launch two payloads in Antarctica in FY 2016. One will study particle acceleration and energy release in solar flares using a combination of high-resolution imaging, spectroscopy, and polarimetry of solar flare gamma ray and hard X-ray emissions. The other will perform large-scale, high-resolution spectroscopic galactic surveys, which will cover a portion of the galactic plane, as well as a deeper survey of galactic arm and inter-arm regions. NASA plans to launch the Compton Spectrometer and Imager (COSI) payload on the 18.8 million-cubic-foot super-pressure balloon from New Zealand in April 2016.

### KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA will continue a competed Astrophysics Research program with emphasis on suborbital payloads and on development of key technologies for use in future missions. Theoretical work will provide the foundation to develop science requirements for new missions.

Three research groups plan to launch Astrophysics experiments on sounding rockets in 2017. One of the experiments will measure the light of the infrared cosmic background that lurks between galaxies. The second will fly an advanced X-ray microcalorimeter detector to obtain high-resolution spectral data from the Puppis A supernova remnant. Another experiment will focus on the extreme-ultraviolet spectrophotometry of nearby B-stars to provide powerful constraints on stellar atmosphere models, and provide key insights towards understanding the reionization of the early universe.

The Balloon project plans to support three campaigns outside the continental U.S., including the annual Antarctic long-duration balloon flights, a launch from Hawaii, and a super-pressure balloon launch from New Zealand, plus one or two domestic campaigns with conventional flights from Palestine, TX and Fort Sumner, NM.

The Antarctic campaign plans to launch three payloads for science investigations. The Hawaii campaign will again support flights for the Space Technology Mission Directorate (STMD) to evaluate new technologies for landing heavy payloads on Mars. One of the planned balloon flights from Fort Sumner will map the cosmic microwave background, and the other will test a new technology for direct imaging of exoplanets.

## Program Elements

### RESEARCH AND ANALYSIS

This project supports basic research, solicited through NASA’s annual Research Opportunities in Space and Earth Sciences (ROSES) announcements. NASA solicits investigations relevant to Astrophysics over the entire range of photon energies, gravitational waves, and particles of cosmic origin. Scientists and technologists from a mix of disciplines review proposals and provide findings that underlie NASA’s merit-based selections.

Astrophysics Research and Analysis solicits technology development for detectors and instruments for potential use on future space flight missions and science and technology investigations using sounding rockets, high-altitude balloons, and similar platforms. A new type of scientific instrument often flies first on a stratospheric balloon mission or on a sounding rocket flight, which takes it briefly outside Earth’s atmosphere. Instruments for balloons and sounding rockets are less expensive than orbital missions, and experimenters can build them quickly to respond to unexpected opportunities, such as a newly discovered comet. The experimenter usually retrieves the equipment after the flight so that novel instruments can be tested, improved, and flown again. Suborbital flights are important for training the next generation of scientists and engineers to maintain U.S. leadership in STEM. The project also supports small experiments to be flown on the ISS, laboratory astrophysics, and limited ground-based observations.

The Astrophysics Theory program element solicits basic theory investigations needed to interpret data from NASA's space astrophysics missions and to develop the scientific basis for future missions. Astrophysics Theory topics include the formation of stars and planets, supernova explosions and gamma-ray bursts, the birth of galaxies, dark matter, dark energy, and the cosmic microwave background.

The Exoplanet Research program element solicits observations to detect and characterize planets around other stars, and their origins.

The Nancy Grace Roman Technology Fellowship develops early career researchers, who could lead future flight instruments and missions. Initially, NASA selects fellows for one year, during which they conduct preliminary work and develop a detailed plan. NASA then selects a subset of fellows for a four-year award to complete the investigation.

The NASA CREAM experiment is a former balloon payload that is operating on the ISS for a mission duration of up to three years. The science goal of the CREAM payload is to extend the energy reach of direct measurements of cosmic rays to the highest energy possible to probe their origin, acceleration, and propagation. The long exposure provided by the ISS above the atmosphere offers more than an order of magnitude improvement in data, yielding much greater statistical accuracy and lower background noise. The University of Maryland in College Park leads the CREAM mission with international collaboration teams from the United States, South Korea, Mexico, and France.

### SMD STEM ACTIVITIES

The FY 2017 budget supports the restructured science education effort resulting from last year's competition, which transitioned from a mission-based education focus to a science discipline focus, consistent with what schools across the Nation teach. During FY 2017, new cooperative agreement awardees will enable scientists and engineers to engage with learners of all ages, supporting the goals of the Federal STEM Education 5-Year Strategic Plan. This restructured education program will reduce fragmentation and will be evaluated to allow for a more streamlined and effective implementation of SMD education efforts. It also will provide a return on the U.S. taxpayer's investment in NASA's scientific research, effectively and efficiently linking NASA science exploration of our home planet, the solar system, and the universe beyond with educational environments.

### BALLOON PROJECT

The Balloon project offers inexpensive, high-altitude flight opportunities for scientists to conduct research and test new technologies before space flight application. Balloon experiments cover a wide range of disciplines in astrophysics, solar physics, heliospheric physics, and Earth upper-atmosphere chemistry as well as selected planetary science, such as comet observations. Observations from balloons have even detected echoes of the Big Bang and probed the earliest galaxies. The Balloon project continues to increase balloon size and enhance capabilities, including an accurate pointing system to allow high-quality astronomical imaging and a SPB that maintains the balloon's integrity at a high altitude to allow much longer flights at mid-latitudes that include nighttime viewing of astronomical objects.

## Program Schedule

The program issues solicitations every year. A Senior Review process assesses all missions in the extended operations phase every two years, and all data archives every three or four years.

| Date | Significant Event |
|---|---|
| Feb 2015 | NASA Research Announcement (NRA) Solicitation |
| Apr 2015 | Senior Review Data Archives |
| Feb 2016 | NRA Solicitation |
| Mar 2016 | Senior Review Operating Missions |
| Feb 2017 | NRA Solicitation |
| Feb 2018 | NRA Solicitation |
| Mar 2018 | Senior Review Operating Missions |
| Apr 2019 | Senior Review Data Archives |
| Mar 2020 | Senior Review Operating Missions |

## Program Management & Commitments

| Program Element | Provider |
|---|---|
| Research and Analysis Project | Provider: All NASA Centers<br>Lead Center: Headquarters (HQ)<br>Performing Center(s): All<br>Cost Share Partner(s): N/A |
| Balloon Project | Provider: Wallops Flight Facility (WFF)<br>Lead Center: WFF<br>Performing Center(s): WFF, HQ<br>Cost Share Partner(s): N/A |

# ASTROPHYSICS RESEARCH

## Acquisition Strategy

NASA issues solicitations for competed research awards each February through ROSES. Panels of scientists conduct peer reviews on all proposals. A Senior Review process reviews all missions in extended operations phase every two years, and all data archives every three or four years.

### MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Balloon Management | Operation of the Columbia Scientific Balloon Facility (CSBF) in Palestine, TX<br>Orbital-ATK | Palestine, TX and other balloon launch sites |

### INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Quality | Archives Senior Review Panel | 2015 | A comparative evaluation of Astrophysics data archives | Recommended improvements in archives | 2019 |
| Quality | Astrophysics Research Program Review Panel | 2011 | Review of competed research projects | Panel praised scope and impact of programs | TBD |
| Quality | Mission Senior Review Panel | 2014 | A comparative evaluation of Astrophysics operating missions | Ranking of missions, citing strengths and weaknesses | 2016, 2018, 2020 |

# OTHER MISSIONS AND DATA ANALYSIS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Astrophysics Directed R&T | 0.0 | -- | **3.7** | 0.2 | 8.4 | 26.4 | 28.1 |
| Contract Administration, Audit & Quality Assurance Services | 15.0 | -- | **14.9** | 15.0 | 15.0 | 15.1 | 15.1 |
| Astrophysics Senior Review | 0.0 | -- | **37.4** | 49.3 | 40.5 | 33.6 | 34.0 |
| Astrophysics Data Program | 17.0 | -- | **17.6** | 17.6 | 17.6 | 17.6 | 17.6 |
| Astrophysics Data Curation and Archival Research | 18.6 | -- | **17.8** | 18.8 | 18.9 | 18.9 | 18.9 |
| **Total Budget** | **50.6** | **--** | **91.4** | **101.0** | **100.3** | **111.6** | **113.6** |

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*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**Launch of the Cosmic Infrared Background ExpeRiment (CIBER) sounding rocket mission from WFF in June 2013 to measure the light of the earliest stars and galaxies. Recently, CIBER detected a surprising surplus of infrared light in the dark space between galaxies, a diffuse cosmic glow as bright as all known galaxies combined..**

The Astrophysics Research program prepares for the next generation of missions through both theoretical research and applied technology investigations. This program uses data from current missions and suborbital science investigations to advance NASA's science goals. One of these goals is to create new knowledge as explorers of the universe, and to use that knowledge for the benefit of all humankind.

## Mission Planning and Other Projects

### DIRECTED RESEARCH AND TECHNOLOGY

This project funds the civil service staff that will work on emerging Astrophysics projects, instruments, and research.

### CONTRACT ADMINISTRATION, AUDIT, AND QUALITY ASSURANCE SERVICES

This project provides critical safety and mission product inspections and contract audit services from the Defense Contract Management Agency and Defense Contract Audit Agency, respectively. It also provides for contract assurance audits, assessments, and surveillance by the NASA Contract Assurance Services Program.

# OTHER MISSIONS AND DATA ANALYSIS

## ASTROPHYSICS SENIOR REVIEW

The Astrophysics Senior Review project enables extension of the life of current operating missions. Every other year, the Astrophysics division conducts a senior review to do comparative evaluations of all operating missions that have successfully completed or are about to complete their prime mission operation phase. The senior review ratings help NASA determine which missions will receive funding for extended operations. The next senior review will take place in spring 2016.

## ASTROPHYSICS DATA ANALYSIS PROGRAM (ADAP)

The Astrophysics Data Analysis Program (ADAP) solicits research that emphasizes the analysis of NASA space astrophysics data archived in the public domain at one of NASA's Astrophysics Data Centers. The size and scope of the archival astronomical data available to ADAP researchers grew dramatically. This increase included data obtained from such major strategic missions as Spitzer and Kepler. In the coming years, the budget will ensure continued, effective use of this scientific resource as data holdings continue to grow from current operating missions, such as Kepler, Fermi, Hubble, Chandra, and the Stratospheric Observatory for Infrared Astronomy (SOFIA).

### Recent Achievements

The number of proposals submitted to ADAP has tripled over the last several years, reflecting a dramatic increase in demand for data from NASA's space astrophysics missions. The research programs supported under the ADAP typically combine data from multiple NASA space astrophysics missions and span a broad range of wavelengths. The multi-mission, multi-wavelength nature of these investigations enables unique science and plays a crucial role in realizing the full scientific potential of NASA's missions. In 2015, the program received 249 compliant proposals in response to its annual solicitation. Of those, NASA selected 51 proposals, spanning the field of astrophysics and exploiting the full range of NASA's archival data holdings for funding.

## ASTROPHYSICS DATA CURATION AND ARCHIVAL RESEARCH (ADCAR)

The Astrophysics Data Centers constitute an ensemble of archives that receives processed data from individual missions and makes them accessible to the scientific community. After the completion of a mission, the relevant, active, multi-mission archive takes over all data archiving activities. Astrophysics Data Curation and Archival Research (ADCAR) covers the activities of the Astrophysics Data Centers and NASA's participation in the Virtual Astronomical Observatory.

### Recent Achievements

The Astrophysics Data Centers are tackling challenges and opportunities presented by a tremendous growth of content. In addition, all the Data Centers are collaborating effectively to establish and operate an integrated infrastructure leading to a NASA Astronomical Virtual Observatory (NAVO). In FY 2015, the Astrophysics Data System Project has expanded its full-text coverage to over 4 million scholarly papers and 80 million citations. The Space Telescope archive had nearly 60 million database searches and delivered nearly 247 terabytes of data to the astronomical community and the public; more than 2,300 scientific publications used the data. New products included the release of the gPhoton interface for Galaxy Evolution Explorer (GALEX) data, Version 1.0 of the Hubble Source Catalog, and community contributed high-level science products. The High Energy Astrophysics Science Archive Center has

## OTHER MISSIONS AND DATA ANALYSIS

released a major new version of its mission-independent data analysis tool, HEASoft. This version adds extensive scripting support to its cloud-based data analysis environment, enabling astronomers to undertake sophisticated automated analyses of large datasets, even full mission archives. The Infrared Science Archive (IRSA) responded to over 13 million user queries in FY 2015, the most in its history. In FY 2015, IRSA upgraded the service to support the powerful Virtual Observatory Table Access Protocol. IRSA data releases included the first year of data from the Near Earth Object Wide-field Infrared Survey Explorer (NEOWISE) reactivation; the second all-sky Planck public release; and newly processed large-format mosaics of Two Micron All Sky Survey (2MASS) images. This year the NASA Extragalactic Database (NED) project gathered and joined key information from about 4,000 new catalogs and journal articles. In FY 2015, NED responded to 59 million web queries, and more than 700 peer-reviewed publications acknowledged use of NED, raising the total to 11,900 such citations to date

# COSMIC ORIGINS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Hubble Space Telescope Operations | 98.6 | -- | **97.3** | 98.3 | 98.3 | 98.3 | 98.3 |
| Stratospheric Observatory for Infrared Astronomy (SOFIA) | 70.0 | -- | **83.8** | 84.8 | 84.8 | 84.8 | 84.8 |
| Other Missions and Data Analysis | 32.4 | -- | **17.4** | 15.3 | 14.2 | 12.4 | 26.4 |
| **Total Budget** | **201.0** | -- | **198.5** | **198.4** | **197.3** | **195.5** | **209.5** |

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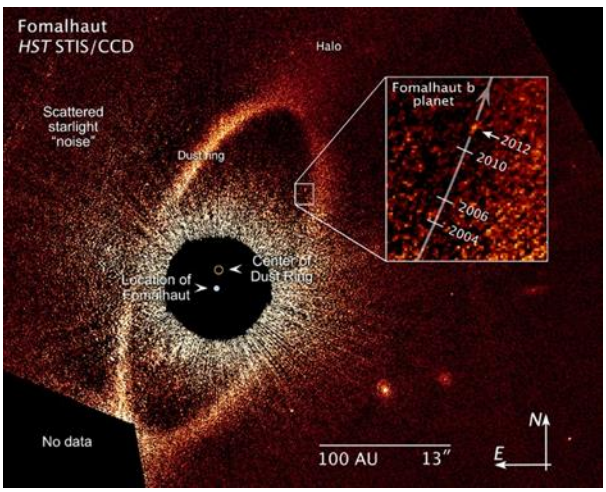



**Hubble images of a vast debris disk encircling the nearby star Fomalhaut, and of a mysterious planet circling it, may provide forensic evidence of a titanic planetary disruption in the system. The latest Hubble images have allowed a team of astronomers to calculate that the planet follows an unusual elliptical orbit that carries it on a potentially destructive path through the vast dust ring.**

"How did we get here?" This simple but fundamental question drives the broad science objectives of NASA's Cosmic Origins program. Our search for an answer raises underlying questions and topic areas, such as, how and when did the first stars and galaxies form? When did the universe first create the elements critical for life? How did galaxies evolve from the very first systems to the types we observe "in the here and now," such as the Milky Way in which we live? How do stars and planetary systems form and change over time?

No individual space observatory or airborne observatory can completely address all of these questions, but in partnership, they can begin to unravel the answers. Currently operating facilities in the Cosmic Origins program are the Hubble Space Telescope, Spitzer Space Telescope, and SOFIA. Working collectively across a wide swath of wavelengths, from the far-ultraviolet through the far-infrared and sub-millimeter, these observatories create a comprehensive web of information and data that spans both the electromagnetic spectrum and time itself.

For more information, see: http://cor.gsfc.nasa.gov/.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

The budget reflects ongoing support for the Hubble Space telescope and the SOFIA project.

# HUBBLE SPACE TELESCOPE OPERATIONS

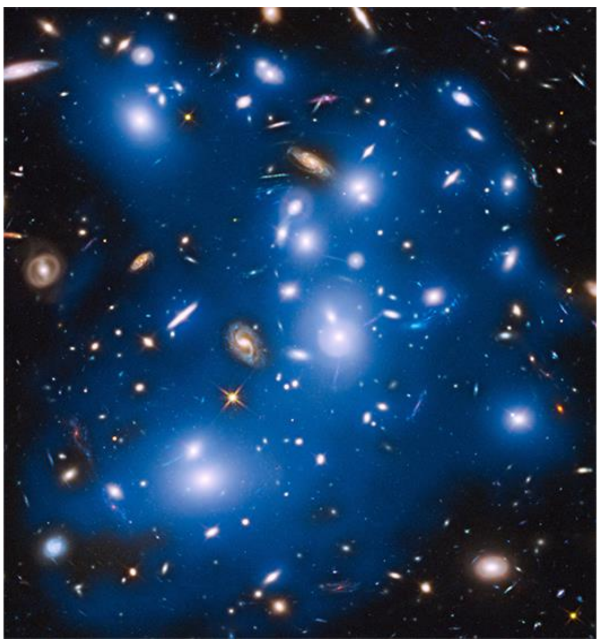
| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | 98.6 | -- | 97.3 | 98.3 | 98.3 | 98.3 | 98.3 |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**When galaxies group together in massive clusters, some of them can be ripped apart by the gravitational tug of other galaxies. Astronomers using the Hubble Space Telescope to probe the massive galaxy cluster Abell 2744, nicknamed Pandora's Cluster, have found forensic evidence of galaxies torn apart long ago in the form of a phantom-like faint glow, filling the space between the galaxies. This glow comes from stars scattered into intergalactic space because of a galaxy's disintegration.**

One of NASA's most successful and long-lasting science missions, the Hubble Space Telescope, has beamed hundreds of thousands of images back to Earth, helping resolve many of the great mysteries of astronomy. The telescope helped scientists determine the age of the universe, the identity of quasars, and the existence of dark energy. Hubble launched in 1990 and is currently in an extended operations phase. The fourth servicing mission by a Space Shuttle crew, completed in 2009, added new batteries, gyroscopes, and instruments to extend Hubble's life even further into the future.

April 24, 2015, marked the start of Hubble's 25th year in orbit. The observatory is currently in its most scientifically productive period.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## ACHIEVEMENTS IN FY 2015

Scientists using Hubble have produced new global maps of Jupiter. These maps are the first in a series of annual portraits of the solar system's outer planets from the Outer Planet Atmospheres Legacy program. Hubble observations confirmed that Jupiter's Great Red Spot weather system continues to shrink and become more circular. The collection of maps to be obtained over time will not only help scientists understand the atmospheres of giant planets in our solar system but also the atmospheres of planets orbiting other stars.

# HUBBLE SPACE TELESCOPE OPERATIONS

| Formulation | Development | Operations |
| --- | --- | --- |

## WORK IN PROGRESS IN FY 2016

In FY 2016 and beyond, NASA will support mission operations, systems engineering, software maintenance, ground systems support, and guest-observer science grants. Work continues on mission life extension initiatives, such as optimizing the use of Hubble's gyroscopes. Hubble will participate in the Astrophysics Senior Review of Operating Missions in spring 2016.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

The Space Telescope Science Institute (STScI), which manages Hubble's science program, will select Cycle 25 science observations. Similar to other recent competitions for Hubble observing time, NASA expects requested observational orbits to outnumber the available orbits by a factor of six to one, indicating that Hubble remains one of the world's preeminent astronomical observatories.

## Project Schedule

| Date | Significant Event |
| --- | --- |
| Jun 2016 | Announcement of Selected Cycle 24 Investigations |
| Dec 2016 | Release of Cycle 25 Call for Proposals |

## Project Management & Commitments

| Element | Description | Provider Details | Change from Formulation Agreement |
| --- | --- | --- | --- |
| Observatory Operation | Provides safe and efficient control and utilization of Hubble, maintenance and operation of its facilities and equipment, as well as creation, maintenance, and utilization of Hubble operations processes and procedures | Provider: Lockheed Martin<br>Lead Center: GSFC<br>Performing Center(s): GSFC<br>Cost Share Partner(s): N/A | N/A |

# HUBBLE SPACE TELESCOPE OPERATIONS

| Formulation | Development | Operations |
|---|---|---|

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| Science Management | Evaluates proposals for telescope time and manages the science program | Provider: STScI/Association of Universities for Research in Astronomy (AURA)<br>Lead Center: GSFC<br>Performing Center(s): GSFC<br>Cost Share Partner(s): European Space Agency (ESA) | N/A |

## Acquisition Strategy

NASA competes all new Hubble research opportunities.

### MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Observatory Operation | Lockheed Martin | Littleton, CO |
| Science Management | STScI/AURA | Baltimore, MD |

### INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | Senior Review | 2016 | Evaluate efficiency and productivity of Hubble operations | Maximize Hubble science return and reliability within available resources | 2018, 2020, 2022 |

# STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | FY 2018 | Notional FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **70.0** | **--** | **83.8** | **84.8** | **84.8** | **84.8** | **84.8** |

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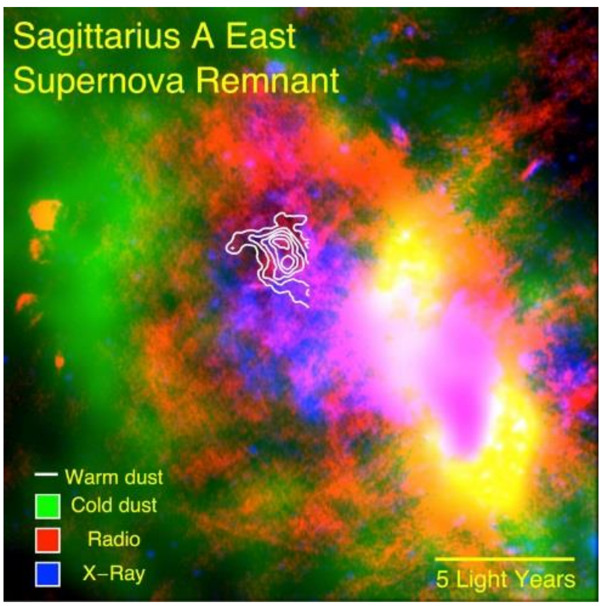



**Dust plays a surprisingly important role in the universe by providing meeting places for atoms to form key molecules and by radiating heat from collapsing clouds to aid in star formation. SOFIA's detection of dust (white lines) having survived the reverse-shock in a supernova remnant affirmatively answered the question regarding whether supernovas are the factories of the very first dust grains in the universe.**

SOFIA is an airborne astronomical observatory that provides the international research community with access to infrared data unattainable from both ground-based and space telescopes. The images, spectra and polarimetry have significant scientific value due to their coverage of mid- to far-infrared wavelengths. SOFIA investigates the cycle of material in the universe by peering through veils of dust to reveal physical phenomena hidden at other wavelengths. These wavelengths are key to unlocking questions regarding:

- the earliest phases of star birth;
- the formation of new planetary systems and implications for life-supporting conditions;
- dust grain production;
- space chemistries of life-sustaining molecules like water;
- the composition of comets and asteroids, which are ancient relics from our own solar system and provide clues to its beginnings; and
- physical properties of planets both near and far (exoplanets), which provide context in understanding the habitability of our own Earth.

SOFIA officially entered the operations phase in May 2014.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

NASA intends for SOFIA to participate in the 2018 Astrophysics Senior Review.

# STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

| Formulation | Development | Operations |
|---|---|---|

## ACHIEVEMENTS IN FY 2015

Researchers used SOFIA to solve a long-standing question regarding the origin of dust in the early universe, by detecting dust that survived a reverse-shock in a supernova remnant. This detection demonstrated that supernovas indeed produce more dust than they destroy, and are therefore the first dust factories. In another investigation, SOFIA observations of newly formed Sun-like stars indicated that their formation had taken a much longer time than expected, suggesting factors that inhibit star formation were at play. Another study performed a highly coordinated observation of a Pluto occultation, providing nearly simultaneous and synergetic data with the New Horizons flyby of Pluto.

Germany completed the heavy maintenance of the SOFIA aircraft in November 2014. SOFIA completed Cycle 2 observations in FY 2015. In mid-June through July 2015, NASA conducted a six-week deployment to the Southern Hemisphere to observe astronomical objects that are not visible in the skies from SOFIA’s home base in California. Three new science instruments completed commissioning flights and began providing data to investigators: Echelon-Cross-Echelle Spectrograph, Far Infrared Field-Imaging Line Spectrometer, and Upgraded German REceiver for Astronomy at Terahertz Frequencies (upGREAT).

## WORK IN PROGRESS IN FY 2016

SOFIA is nearing the completion of Cycle 3 observations in FY 2016, with the start of Cycle 4 observations planned for March 2016. The project will commission a second new observing mode of upGREAT, a second-generation science instrument, in December 2015. NASA plans interim baseline commissioning and science observations using the High-resolution Airborne Wideband Camera (HAWC+), the remaining second-generation instrument, in mid-FY 2016. The procurement of a third-generation science instrument is underway, with the selection of a proposed, competed instrument concept, planned for FY 2016. The SOFIA Science Operations contract will be re-competed this year. A request for proposal is under preparation now and NASA will release it in FY 2016.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

SOFIA will begin to conduct Cycle 5 observations in FY 2017, following a competed selection process. Cycle 5 will include a Southern Hemisphere deployment involving a suite of science instruments that optimizes science demand. The development phase for the selected third-generation science instrument will begin in FY 2017. SOFIA will award a new primary contract for its Science Mission Operations in FY 2017.

# STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

| Formulation | Development | Operations |
|---|---|---|

## Project Schedule

| Date | Significant Event |
|---|---|
| Apr 2016 | Release of Cycle 5 Call for Proposals |
| Oct 2016 | Announcement of Selected Cycle 5 Investigations |

## Project Management & Commitments

The Ames Research Center (ARC) manages SOFIA.

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| Science Operations Center | Science Operations Center will solicit and select new investigations, schedule observations, and manage data acquisition and processing | Provider: ARC/Universities Space Research Association (USRA)<br>Lead Center: ARC<br>Performing Center(s): ARC<br>Cost Share Partner(s): German Aerospace Center (DLR)/Deutsches SOFIA Institute (DSI) | N/A |
| Flight Operations | Flight crew, maintenance, and fuel | Provider: Armstrong Flight Research Center (AFRC)/Computer Sciences Corporation (CSC) DynCorp<br>Lead Center: AFRC<br>Performing Center(s): AFRC<br>Cost Share Partner(s): DLR/DSI | N/A |
| Upgraded HAWC+ | HAWC+ far-infrared camera to be upgraded with the addition of polarimetry capability and new state of the art detectors | Provider: Jet Propulsion Laboratory (JPL), GSFC<br>Lead Center: ARC<br>Performing Center(s): JPL, GSFC<br>Cost Share Partner(s): N/A | N/A |
| SOFIA Program Management | Program management functions transferred | ARC as lead Center | Yes |

# STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

| Formulation | Development | Operations |
|---|---|---|

## Acquisition Strategy

The project has awarded all major contracts.

### MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Platform | L3 Communications | Palmdale, CA |
| Cavity Door Drive System | Woodward MPC | Skokie, IL |
| Aircraft Maintenance Support | L3 Vertex Aerospace (under AFRC shared service contract) | Palmdale, CA |

### INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Program Transition Readiness Review (PTRR) | Standing Review Board (SRB) | Jul 2015 | Assess the readiness of the program to transition the management from AFRC to ARC | Transition completed on Oct 1, 2015 | N/A |
| Quality | Mission Senior Review | N/A | Evaluate operations efficiency, merit of science case, and scientific productivity | Ranking of SOFIA science return and reliability within available resources | 2018 |

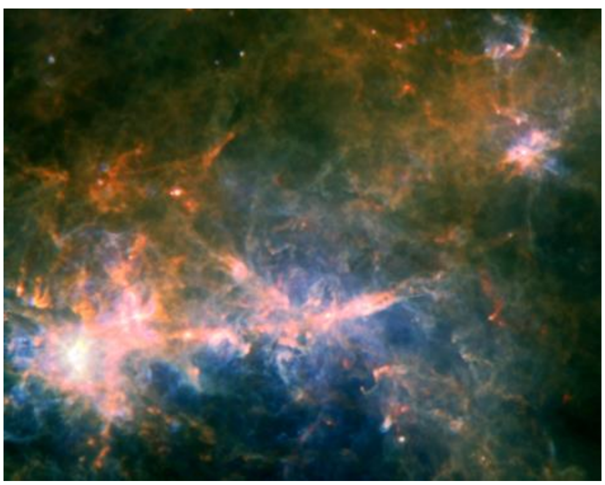
# OTHER MISSIONS AND DATA ANALYSIS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Cosmic Origins Program Management | 2.6 | -- | **2.5** | 2.9 | 2.9 | 2.9 | 2.9 |
| Cosmic Origins SR&T | 8.8 | -- | **9.3** | 10.9 | 9.8 | 8.0 | 22.0 |
| Cosmic Origins Future Missions | 1.2 | -- | **1.1** | 1.5 | 1.5 | 1.5 | 1.5 |
| SIRTF/Spitzer | 14.6 | -- | **3.5** | 0.0 | 0.0 | 0.0 | 0.0 |
| Herschel | 5.1 | -- | **1.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| **Total Budget** | **32.4** | **--** | **17.4** | **15.3** | **14.2** | **12.4** | **26.4** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**New images of huge filamentary structures of gas and dust from the Herschel space observatory reveal the distribution of matter across our Milky Way galaxy. Long and flimsy threads emerge from a twisted mix of material, taking on complex shapes. This image shows a filament called G49, which contains 80,000 Suns' worth of mass. This huge but slender structure of gas and dust extends about 280 light years in length, while its diameter is only about five light years across. In the densest and coolest clumps, which appear red, the seeds of new generations of stars are taking shape.**

Other Missions and Data Analysis supports the Spitzer Space Telescope, the scientific applications of which continue to expand, as well as NASA's partnership with ESA on the Herschel mission. Spitzer determined the mass and age of the youngest known galaxies, seen as they were when the universe was one-tenth or less of its current size and age. Herschel has shown that our galaxy contains abundant filamentary structures on length scales from a few light years to many hundreds. The science team expects many more discoveries over the next several years as they analyze data from both observatories.

## Mission Planning and Other Projects

### COSMIC ORIGINS PROGRAM MANAGEMENT

Cosmic Origins (COR) program management provides programmatic, technical, and business management, as well as program science leadership.

# OTHER MISSIONS AND DATA ANALYSIS

### Recent Achievements

The COR program office conducted an updated analysis of Hubble disposal timing and requirements. The program office verified a drift rate analysis of the telescope at lower altitudes and monitored relevant technologies. Under the current solar cycle conditions, the study concluded that the worst-case scenario for Hubble re-entry into the atmosphere is no earlier than FY 2027, and is most likely to occur around FY 2036.

## COSMIC ORIGINS STRATEGIC RESEARCH AND TECHNOLOGY (SR&T)

COR Strategic Research and Technology (SR&T) supports program-specific research and advanced technology development efforts, such as the Strategic Astrophysics Technology solicitation issued in FY 2014. In addition, funding supports the study of a future ultraviolet/optical space capability.

### Recent Achievements

The COR program released its updated Program Annual Technology Report. This report summarizes the status of technology development funded by the program in prior years and in FY 2015. This report describes the prioritization of future technology needs.

A copy of the report is available at http://cor.gsfc.nasa.gov/docs/2015CORPATRRev1.pdf.

## COSMIC ORIGINS FUTURE MISSIONS

COR Future Missions funding supports studies of future mission concepts.

### Recent Achievements

The program is engaging with the scientific community to lay the groundwork to mature mission concept studies and technology development that will eventually provide inputs to the 2020 Astronomy and Astrophysics Decadal Survey.

# Operating Missions

## SPITZER

The Spitzer Space Telescope, launched in 2003 as the final element of NASA's series of Great Observatories, is now in extended operations. Spitzer is an infrared telescope that uses two channels of the Infrared Array Camera instrument to study exoplanet atmospheres, early clusters of galaxies, near-Earth asteroids, and a broad range of other phenomena. Spitzer completed its cryogenic mission in FY 2009, and extended warm operations through FY 2014. NASA accepted the 2014 Senior Review of Operating Missions recommendation to continue Spitzer operations through FY 2016.

### Recent Achievements

Astronomers using Spitzer observed a wide range of objects from within the solar system to the distant regions of the universe. Spitzer detected the transit of the innermost of four planets that orbit the nearby

# OTHER MISSIONS AND DATA ANALYSIS

star HD 219134. Scientists estimate the planet’s mass and radius to be about 4.5 times the mass of Earth and 1.6 times the radius of Earth. HD 219134b is the nearest known rocky exoplanet. The Spitzer mission and the ground-based Optical Gravitational Lensing Experiment (OGLE) both observed a microlensing event involving two stars, with the more distant, lensed star having a planetary companion. Because of the large spatial separation between Spitzer and Earth, Spitzer saw the event 20 days earlier than OGLE. The time delay led to an estimated distance of 13,000 light years to the lensed star-planet system, making the planet one of the most distant exoplanets known. Based on the results of this pilot project, all of June 2015 was dedicated to microlensing observations, coordinated with ground-based surveys. Spitzer discovered a giant galaxy at the heart of a massive galaxy cluster, named SpARCS 1049+56 that is forming new stars at an incredible rate: about 800 new stars per year. This is surprising because usually galaxies at the centers of clusters are made of stellar fossils, which are old, red, or dead stars. Scientists believe the increased activity is from a recently swallowed gas-rich galaxy, a first observation of such a merger at the center of a galaxy cluster. Spitzer observations combined with data from Hubble and the Keck telescope have precisely measured the distance of the furthest galaxy discovered to date. The age of galaxy EGS-zs8-1 is only 670 million years after the Big Bang and it is already very massive for its age, containing as much as 15 percent of the mass of Milky Way galaxy.

## HERSCHEL

The Herschel Space Observatory is a collaborative mission with ESA that launched on May 14, 2009. Herschel can detect the coldest and dustiest objects in space, such as cool cocoons where stars form and dusty galaxies bulk up with new stars. Herschel has the largest single mirror ever built for a space telescope and collects long wavelength radiation from some of the coldest and most distant objects in the universe. NASA contributed key technologies to two instruments onboard Herschel, and hosts U.S. astronomer access to data through the NASA Herschel Science Center. Herschel’s onboard supply of helium expired in the middle of FY 2013, and the focus of the mission turned to analysis of the vast stores of data already obtained.

### Recent Achievements

Although the Herschel Space Observatory ended astronomical observations upon cryogen exhaustion on April 29, 2013, the NASA Herschel Science Center continues development of data analysis software in collaboration with the ESA Herschel Science Center. The NASA Herschel Science Center continues to host activities that inform the Herschel Space Observatory user community on data analysis techniques and the use of the science mission archives. Herschel data uncovered extreme star formation rates in the core of distant galaxy clusters, previously thought to have been otherwise devoid of new stars. Another recent result from Herschel data analysis has provided proof that the strong winds blown by a supermassive black hole at the center of a galaxy can quench its star formation. In FY 2015, Herschel and Planck received the Space Systems Award from the American Institute of Aeronautics and Astronautics for “outstanding scientific achievements recognized by the worldwide scientific community and for outstanding technical performances of the two satellites.”

# PHYSICS OF THE COSMOS

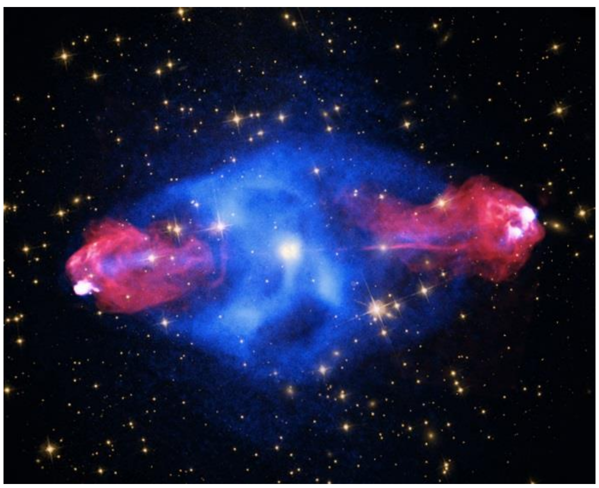
## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Other Missions and Data Analysis | 104.1 | -- | **94.1** | 88.0 | 94.1 | 97.7 | 94.0 |
| **Total Budget** | **104.1** | **--** | **94.1** | **88.0** | **94.1** | **97.7** | **94.0** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*



**Images of the galaxy Cygnus A shows the dramatic impact of a supermassive black hole on its surroundings. Relativistic jets of particles accelerate from the vicinity of black hole, and punch giant holes in hot gas, detected with NASA's Chandra X-ray Observatory (blue). Radio data from the Very Large Array (red) reveal "hot spots" of light hundreds of thousands light years away from the center of the galaxy. Visible light data (yellow) from Hubble and Sloan Digital Sky Survey (SDSS) complete this view. Credit: X-ray: NASA/CXC/SAO; Optical: NASA/STScI; Radio: NSF/NRAO/AUI/VLA.**

The universe can be viewed as a laboratory that enables scientists to study some of the most profound questions at the intersection of physics and astronomy. How do matter, energy, space, and time behave under extreme gravity? What is the nature of dark energy and dark matter? How did the universe grow from the Big Bang to its present size? The Physics of the Cosmos (PCOS) program incorporates cosmology, high-energy astrophysics, and fundamental physics projects that address central questions about the nature of complex astrophysical phenomena, such as black holes, neutron stars, dark matter and dark energy, cosmic microwave background, and gravitational waves.

The operating missions within the PCOS program continue to provide answers to these fundamental questions and more. Scientists using data from the Fermi mission are trying to determine what comprises dark matter and how black holes accelerate immense jets of material to nearly the speed of light. The Planck mission observed the earliest moments of the universe and provided a high-resolution map of the cosmic microwave background. The X-ray Multi-Mirror Mission (XMM-Newton) is helping scientists solve cosmic mysteries, including enigmatic massive black holes. The Chandra X-Ray Observatory mission continues to reveal new details of celestial X-ray phenomena, such as the collisions of clusters of galaxies that directly detect the presence of dark matter. It unveiled a population of faint, obscured, massive black holes that may provide the early seeds for galaxy formation and growth since the birth of the universe nearly 14 billion years ago.

# PHYSICS OF THE COSMOS

PCOS includes a vigorous program to develop the technologies necessary for the next generation of space missions to address the science questions of this program.

For more information, see: http://nasascience.nasa.gov/about-us/smd-programs/physics-of-the-cosmos.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Mandatory Budget Authority** | -- | -- | 6.0 | -- | -- | -- | -- |

Physics of the Cosmos is supported in part with mandatory funding. The mandatory investment includes $6 million for PCOS SR&T. The PCOS SR&T increase is to prepare for the next generation of PCOS space missions and continue discussions with ESA on a partnership on their Large 2 (Athena) and Large 3 (Gravitational Waves) missions.

The budget for Euclid increased due to a delay in the ESA schedule and an increase in the cost of the U.S.-provided detectors.

# OTHER MISSIONS AND DATA ANALYSIS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Physics of the Cosmos SR&T | 12.0 | -- | **25.4** | 18.5 | 23.7 | 23.8 | 23.9 |
| Euclid | 7.5 | -- | **12.9** | 7.5 | 7.7 | 9.9 | 6.1 |
| Physics of the Cosmos Program Management | 3.0 | -- | **2.9** | 3.2 | 3.2 | 3.2 | 3.2 |
| Physics of the Cosmos Future Missions | 0.1 | -- | **0.5** | 2.1 | 2.1 | 2.5 | 2.5 |
| Fermi Gamma-ray Space Telescope | 16.9 | -- | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| Chandra X-Ray Observatory | 55.6 | -- | **52.4** | 56.7 | 57.4 | 58.4 | 58.4 |
| XMM | 2.9 | -- | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| Planck | 6.0 | -- | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| **Total Budget** | **104.1** | **--** | **94.1** | **88.0** | **94.1** | **97.7** | **94.0** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*


**The Laser Interferometer Space Antenna (LISA) Pathfinder mission undergoes preparations ahead of its launch from Kourou, French Guiana. NASA is contributing the Space Technology (ST) 7, which will use precision microthrusters to demonstrate that a solid body can float freely in space completely undisturbed. Credit: ESA-CNES-Arianespace/Optique.**

Other Missions and Data Analysis supports PCOS SR&T, PCOS Program Management, PCOS Future Missions, Euclid, Fermi, Chandra, XMM-Newton, and Planck.

## Mission Planning and Other Projects

### PCOS SUPPORTING RESEARCH AND TECHNOLOGY

PCOS Supporting Research and Technology includes Einstein Fellowships and strategic technology development efforts, to prepare for the next generation of PCOS space missions and continue discussions with ESA on a partnership on their Large 2 (Athena) and Large 3 (Gravitational Waves) missions with a goal to define the partnerships. The Space Technology (ST) 7 project launched on the ESA LISA Pathfinder mission in December 2015. NASA contributed enhanced thrusters that will apply thrust equivalent to the weight of a single grain of sand, and are a key component of the LISA Pathfinder gravitational technology demonstration experiment.

# OTHER MISSIONS AND DATA ANALYSIS

### Recent Achievements

The PCOS program released its updated Program Annual Technology Report. This report summarizes the status of technology development funded by the program in FY 2015 and describes the prioritization of future technology needs.

A copy of the report is at: http://pcos.gsfc.nasa.gov/docs/2015PCOSPATRRev1.pdf.

## EUCLID

NASA is collaborating on Euclid, an ESA mission, selected as part of ESA's Cosmic Visions program in June 2012 and scheduled for launch in 2020. Euclid seeks to investigate the accelerated expansion of the universe, the so-called "dark energy," using a Visible Instrument and a Near Infrared Spectrometer and Photometer instrument, as well as ground-based data. The Euclid Consortium, comprised of over 1,200 scientists and engineers from over 50 institutes in Europe, the United States, and Canada, is responsible for development of the two instruments and the Science Data Centers. NASA contributes flight detector subsystems for the Near Infrared Spectrometer and Photometer instrument, and a NASA Euclid Science Center that forms part of the Euclid Science Ground System. In exchange, NASA receives membership in the Euclid Science Team and Consortium, and competed science opportunities for U.S. investigators.

### Recent Achievements

NASA signed a contract with Teledyne in January 2015 to provide flight detectors for the Euclid mission.

## PCOS PROGRAM MANAGEMENT

PCOS program management provides programmatic, technical, and business management, as well as program science leadership.

### Recent Achievements

The NASA Astrophysics Division (APD) is pursuing a partnership with ESA on their Large 2 mission, Athena, an X-ray observatory dedicated to high-resolution spectroscopy. The details of the contribution are still under discussion. PCOS is leading the management of this contribution.

APD is also pursuing a partnership with ESA on their Large 3 mission concept, a Gravitational Wave observatory, by assembling a Community Science Team to define options for NASA contributions. NASA will solicit membership for the Community Science Team in an open call in 2016.

## PCOS FUTURE MISSIONS

PCOS Future Missions funding supports concept studies of future missions.

### Recent Achievements

The PCOS program is engaging with the scientific community to lay the groundwork for design studies and technology development that will eventually provide inputs to the 2020 Astronomy and Astrophysics Decadal Survey.

# OTHER MISSIONS AND DATA ANALYSIS

## Operating Missions

### FERMI

The Fermi Gamma-ray Space Telescope explores extreme environments in the universe, from black holes to gamma ray bursts, to expand knowledge of their high-energy properties. Fermi data are answering long-standing questions across a broad range of topics, including solar flares, the origin of cosmic rays, and the nature of dark matter. Fermi, a NASA mission with strong international and Department of Energy involvement, launched in June 2008. Fermi entered extended mission operations in August 2013.

#### Recent Achievements

Recent notable accomplishments by Fermi include the identification of classical novae as gamma-ray sources, the detection of a record-setting gamma-ray flare and rapid flare variability in the blazar 3C 279 (a galaxy whose high-energy activity is powered by a central supermassive black hole), and the discovery of the first extragalactic gamma-ray pulsar. The project released the third Fermi Large Area Telescope source catalog in 2015, containing 3,033 sources, as well as the Pass 8 version of the Fermi Large Area Telescope data, embodying many improvements that will significantly enhance Fermi science.

### CHANDRA

Launched in 1999, Chandra is transforming our view of the universe with its high quality X-ray images, providing unique insights into violent events and extreme conditions such as explosions of stars, collisions of galaxies, and matter around black holes. Chandra enables observations of clusters of galaxies that provide direct evidence of the existence of dark matter, and greatly strengthens the case for the existence of dark energy. Chandra observations of the remains of exploded stars, or supernovas, have advanced our understanding of the behavior of matter and energy under extreme conditions. Chandra also discovered and studied hundreds of supermassive black holes in the centers of distant galaxies. Chandra will be included in the Astrophysics Senior Review of Operating Missions in spring 2016.

#### Recent Achievements

With its unique vision of some of the hottest and most energetic phenomena in the cosmos, Chandra delivered several outstanding results over the past year. In combination with NASA's Swift Gamma-ray Burst Explorer and ESA/NASA's XMM-Newton, Chandra collected different pieces of an astronomical puzzle when a black hole in the galaxy PGC 043234 tore apart and destroyed a star as it came too close to the black hole. The close encounter produced copious amounts of X-rays, which advanced our understanding of the structure and evolution of tidal disruption events and the effects of extreme gravity. Chandra made an unexpected discovery of the largest X-ray flare ever detected from the supermassive black hole at the center of the Milky Way galaxy, called Sagittarius A*. This "megaflare" was nearly 200 times brighter than the previous brightest X-ray flare from Sagittarius A*, and the brightest outburst observed over the last 15 years. Chandra has also helped identified the smallest supermassive black hole ever detected in the center of a galaxy. The black hole at the center of the galaxy RGG 118 is less than half the mass of the previous smallest black hole at the center of a galaxy, and about 100 times less massive than the supermassive black hole found in the center of the Milky Way.

Observations with Chandra also showed that a fast-moving pulsar appears to have punched a hole in a disk of gas around its companion star and launched a fragment of the disk outward at a speed of about 40 million miles per hour. The double star system B1259 contains a star about 30 times as massive as the Sun and a pulsar, an ultra-dense neutron star left behind when an even more massive star underwent a supernova explosion. As the pulsar makes its closest approach to the star every 41 months, it passes through this disk, knocking out parts of the disk.

A study using Chandra also showed that the growth of galaxies containing supermassive black holes could slow due to a phenomenon referred to as cosmic precipitation. The study looked at some of the largest known galaxies lying in the middle of galaxy clusters. These galaxies exist within enormous atmospheres of hot gas. This hot gas should cool and many stars should then form. However, observations show that some of the gas is raining onto the supermassive black hole, triggering jets of energetic particles that push against the falling gas and reheat it, preventing more stars from forming. This cycle of cooling and heating creates a feedback loop that regulates the growth of the galaxies.

## X-RAY MULTI-MIRROR MISSION (XMM-NEWTON)

XMM-Newton, an ESA-led mission with substantial NASA contributions, launched in December 1999. XMM-Newton provides unique data for studies of the fundamental processes of black holes and neutron stars. It studies the evolution of chemical elements in galaxy clusters and the distribution of dark matter in galaxy clusters and elliptical galaxies.

### Recent Achievements

During the past year, XMM-Newton observations yielded a number of important new science results. In concert with Chandra, XMM-Newton has detected the last “cry” from a star that passed too close to the central black hole of its host galaxy and was being destroyed and ‘swallowed,’ a phenomenon known as a tidal disruption event. The study, based on the observations of X-rays emitted by leftover material from the star in the vicinity of the black hole, allowed astronomers to measure, for the first time, the physical properties of a newly formed accretion disc, enabling them to investigate the initial phases of such a powerful event. Recent observations of the galaxy cluster RXCJ2359.5-6042 with the XMM-Newton reveal evidence for an ongoing merger that strips the smaller system of much of its gas. A new mosaic image by XMM-Newton confirms powerful remnants of dead stars and their immense effect on the surrounding gas reveals some of the most intense processes taking place at the center of the Milky Way. Using data from XMM-Newton and Chandra, astronomers have discovered a bright X-ray light echo in the form of four well-defined rings around the neutron star. These rings are about 30,700 light years from Earth. XMM-Newton and the Nuclear Spectroscopic Telescope Array (NuSTAR) observations have revealed that the winds from supermassive black holes at the center of galaxies blast out in all directions, supporting the picture of black holes having a significant impact on star formation of their host galaxy.

## PLANCK

Planck’s objective is to analyze, with the highest accuracy ever achieved, the remnants of radiation that filled the universe immediately after the Big Bang. Planck enables scientists to address fundamental questions, such as the initial conditions for the evolution of the universe, the overall geometry of space, the rate at which the universe is expanding, and the nature and amount of the constituents of the universe. Planck, launched in May 2009, is an ESA-led telescope with substantial NASA contributions. In October 2013, having already placed the spacecraft in its final heliocentric orbit, ESA ended mission operations.

# OTHER MISSIONS AND DATA ANALYSIS

NASA accepted the 2014 Senior Review of Operating Missions recommendation to continue Planck data analysis and archival activities through FY 2016.

### Recent Achievements

In FY 2015, the Planck team released its second catalog of compact sources, including polarization data for most of them, completing the 2015 archival data delivery. The team continues to submit scientific papers for publication in peer-reviewed journals. In September 2015, the team received the American Institute of Aeronautics and Astronautics Space Systems Award.

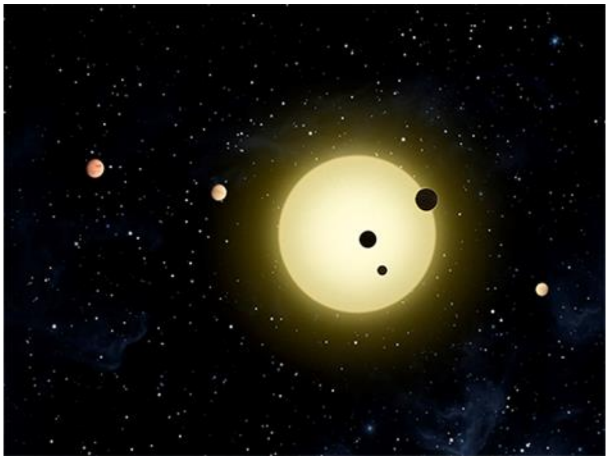
# EXOPLANET EXPLORATION

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Other Missions and Data Analysis | 100.6 | -- | 133.8 | 148.0 | 309.3 | 373.3 | 450.8 |
| **Total Budget** | **100.6** | **--** | **133.8** | **148.0** | **309.3** | **373.3** | **450.8** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**Two new exoplanets, Kepler 20e and 20f, are part of a five-planet system orbiting a sun-like star, similar to the artist's rendering above.**

Humankind stands on the threshold of a voyage of unprecedented scope and ambition, promising insight into timeless questions: Are we alone? Is Earth unique, or are planets like ours common? One of the most exciting new fields of research within the NASA Astrophysics portfolio is the search for planets, particularly Earth-like planets, around other stars.

Since the discovery of the first exoplanets in the mid-1990s, astronomers have discovered over 1,900 planets orbiting stars of all shapes and sizes in our galaxy. At first, most of the planets discovered were so-called "Hot Jupiters"—gas giants similar in size to the planet Jupiter, but orbiting much closer to their parent stars. However, analysis of the complete Kepler data set suggests that smaller planets—with sizes in the Earth-to-Neptune range—are actually more common. Rocky planets in the habitable zone of their parent stars appear to be common. NASA's Exoplanet Exploration program is advancing along a path of discovery leading to a point where scientists can directly study the atmospheres and surface features of habitable, rocky planets, like Earth, around other stars in the solar neighborhood.

In the future, NASA aims to develop systems that will allow scientists to take the pivotal step from identifying an exoplanet as Earth-sized to determining whether it is truly Earth-like, and possibly even detecting if it bears the fingerprints of life. Such an ambitious goal includes significant technological challenges. An important component of the Exoplanet Exploration effort is a robust technology development program with the goal of enabling a future direct detection mission.

For more information, go to http://exep.jpl.nasa.gov/.

# EXOPLANET EXPLORATION

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Mandatory Budget Authority** | -- | -- | 76.0 | -- | -- | -- | -- |

Exoplanet exploration is supported in part with mandatory funding. The mandatory investment includes $76 million for the Astrophysics Decadal Strategic Mission.

The FY 2017 request supports mission formulation for the Wide Field Infrared Survey Telescope (WFIRST), the highest-priority large mission from the NRC 2010 Astronomy and Astrophysics Decadal Survey. The budget request also reflects a new partnership between NASA and the National Science Foundation to detect and measure the mass of exoplanets via precision radial velocity measurements using the Wisconsin–Madison, Indiana University, Yale University, and National Optical Astronomy Observatory (WIYN) telescope.

# OTHER MISSIONS AND DATA ANALYSIS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Astrophysics Decadal Strategic Mission | 50.0 | -- | **90.0** | 108.2 | 267.7 | 331.8 | 409.9 |
| Exoplanet Exploration SR&T | 19.4 | -- | **28.0** | 26.5 | 27.6 | 26.9 | 26.2 |
| Exoplanet Exploration Program Management | 5.1 | -- | **5.1** | 6.0 | 5.9 | 6.3 | 6.4 |
| Exoplanet Exploration Future Missions | 0.9 | -- | **0.5** | 1.1 | 8.2 | 8.3 | 8.3 |
| Keck Operations | 6.0 | -- | **6.1** | 6.2 | 0.0 | 0.0 | 0.0 |
| Large Binocular Telescope Interferometer | 2.0 | -- | **1.3** | 0.0 | 0.0 | 0.0 | 0.0 |
| Kepler | 17.2 | -- | **2.8** | 0.0 | 0.0 | 0.0 | 0.0 |
| **Total Budget** | **100.6** | **--** | **133.8** | **148.0** | **309.3** | **373.3** | **450.8** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*


**Relative sizes of habitable-zone planets discovered by the Kepler spacecraft, shown alongside Earth. NASA-Ames / JPL-Caltech. .**

## Mission Planning and Other Projects

### ASTROPHYSICS DECADAL STRATEGIC MISSION (ADSM)

NASA spent the first half of the current decade studying ways to address the NRC 2010 Astronomy and Astrophysics Decadal Survey's highest-ranked science recommendations in the large and medium categories: the science of WFIRST and the maturation of technology for a potential exoplanet characterization mission. NASA's current concept for the WFIRST mission addresses both of these recommendations. WFIRST formally enters formulation in FY 2016.

#### Recent Achievements

NASA has continued to develop the conceptual design for the WFIRST mission, which utilizes the Astrophysics Focused Telescope Assets (AFTA) transferred to NASA. The design leverages these telescope assets while fully meeting the WFIRST requirements articulated in the decadal survey and potentially enabling additional science opportunities in exoplanet coronagraphy and guest investigator science. NASA has made significant progress in maturing the technology for the exoplanet high-contrast imaging instrument, along with the infrared detector technology required for the wide-field infrared survey.

# OTHER MISSIONS AND DATA ANALYSIS

## EXOPLANET EXPLORATION STRATEGIC RESEARCH AND TECHNOLOGY

Exoplanet Exploration Strategic Research and Technology supports the Sagan Postdoctoral Fellowships, program-specific scientific research, and technology development activities that support and enable future Exoplanet Exploration missions.

In FY 2016, NASA supported approximately 13 competitively selected technology development projects involving 49 different investigators and 22 Sagan Fellows. The selected technology development projects all focus on advancing technologies for separating the feeble reflected light of an exoplanet from the overwhelming glare of its parent star, revealing clues to the planet's nature. Those technologies will one day enable the ultimate goal of NASA's Exoplanet Exploration Program: a future mission capable of imaging and measuring the spectra of habitable, Earth-like exoplanets in the solar neighborhood. Precision radial velocity technologies will enable better measurements of exoplanet masses. These precision radial velocity measurements, in conjunction with the transit photometric information that can provide the exoplanet radii, will result in the determination of exoplanet densities and structures before possible follow-ups in the search of chemical biomarkers of life.

### Recent Achievements

New coronagraph techniques have demonstrated suppression of starlight glare to a few parts per billion and only a few image diameters away from the bright parent star. Coronagraphs and starshades are enabling technologies for the direct detection of exoplanets around stars. They block the light from the stars and, thus, make possible the detection of planets orbiting the parent star. NASA could use this technology in possible future missions, enabling direct imagining of exoplanets and the search for spectral biosignatures. In addition, starshades that are many tens of meters in diameter, an alternative to coronagraphs, require precision dimensional control after a stowed launch. A recent deployment test has shown that the required control and repeatability is achievable.

NASA and the National Science Foundation formalized a new partnership to develop a new precision radial velocity instrument for the WIYN telescope, enabling better measurements of exoplanet masses. Two university-based teams are performing formulation studies of their proposed instrument concepts.

## EXOPLANET EXPLORATION PROGRAM MANAGEMENT

Exoplanet Exploration program management provides programmatic, technical, and business management, as well as program science leadership. Program management coordinates, supports, tracks the progress of the program's numerous technology development tasks, and oversees the program's portfolio of projects.

### Recent Achievements

Scientists have confirmed more than 1,900 exoplanets, with more than 3,700 additional candidates discovered for continuing investigation. Current estimates indicate that perhaps one in ten stars host rocky planets that exist in orbits where water may flow freely upon their surface. The program is managing design studies of mission opportunities and providing oversight of the WFIRST-AFTA concept study. The program is also engaging with the scientific community to lay the groundwork for design studies and technology development that will eventually provide inputs to the 2020 Astronomy and Astrophysics Decadal Survey.

# OTHER MISSIONS AND DATA ANALYSIS

## EXOPLANET EXPLORATION FUTURE MISSIONS

Exoplanet Exploration Future Missions funding supports the execution of the exoplanet mission science and technology definition teams, and ultimately the formulation, development, and implementation of a future Exoplanet Exploration flight mission.

### Recent Achievements

Community-based Science and Technology Definition Teams delivered their final reports on studies of two probe-scale (medium size) exoplanet mission concepts. One concept was a coronagraphic telescope approach and the second was a starshade, flying in long-range formation with a separate free-flying telescope. An associated technical/engineering study group supported each Science and Technology Definition Team. NASA has initiated follow-on tasks to build upon the work of these teams.

# Operating Missions

## KECK OPERATIONS

Keck Operations is the NASA portion of the Keck Observatory partnership. NASA uses its share of observing time in support of Astrophysics and Planetary Science programs. The project allocates observing time for Exoplanet Exploration, Cosmic Origins, and PCOS science goals, as well as solar system objects and direct space missions support. Observation time is competed, selected, and managed by the NASA Exoplanet Science Institute. The Institute recently has awarded a significant portion of the observing time to studies of potential planets identified by Kepler.

### Recent Achievements

NASA is partner for 1/6th of the observing nights with the W.M. Keck Observatory for both 10-meter telescopes. Similarly, the Keck Observatory Archive (KOA), in partnership with the NASA Exoplanet Science Institute, ingests and curates existing and new data from the Keck Observatory. In the past year, the KOA completed the ingestion for all 10 Keck active and decommissioned instruments and made these data available to the community. This archive covers more than 14,000 nights of observations and occupies more than 15 terabytes of astronomical data. More than 15 percent of the scientific papers produced by Keck Observatory rely on archival data retrieved from KOA. In the first semester of 2015, the project received 101 proposals, requesting over 160 nights to use either of the two Keck telescopes in the Single Aperture Mode. This represents an oversubscription of five to one for both Keck telescopes. In the past 7 years, the combined oversubscription has varied from 5.7 to 2.5. In addition, for the first observing semester in 2016 (February 1 to July 31, 2016), NASA solicited Key Strategic Mission Support proposals, and three proposals (representing the disciplines of Exoplanets, Extragalactic and Solar System) have been recommended for selection, which will be allocated a total of 15 nights per semester for the next four semesters.

## LARGE BINOCULAR TELESCOPE INTERFEROMETER

The Large Binocular Telescope Interferometer (LBTI) is the NASA portion of the Large Binocular Telescope partnership. Engineers designed the LBTI to allow high contrast, high spatial resolution infrared imaging of dust clouds around 50 nearby stars. The system surveys nearby stars for dust and debris disks that may hamper the detection of planets around those stars. This information will be crucial for designing future space observatories capable of detecting and characterizing those planets by direct imaging.

### Recent Achievements

LBTI conducted a successful Operations Readiness Review (ORR) in April 2015 and proceeded with the Science Validation Phase. The ORR results demonstrated that operational system performance was likely to be sufficient to meet science objectives.

## KEPLER

Kepler, launched in March 2009, surveys stars in the local region of the Milky Way galaxy to detect and characterize rocky planets in or near the habitable zone of their host star. The habitable zone encompasses the distances from a star where liquid water can exist on a planet's surface. As time progresses, smaller planets with longer orbital periods emerge from the data.

In June 2014, NASA approved Kepler to enter a new phase of operations in which the spacecraft observes along the ecliptic plane, opening up new possibilities for discovery. The 2014 Senior Review of Operating Missions favorably evaluated this new operating mode, which compensates for the loss of an attitude control actuator.

### Recent Achievements

In July 2015, the Kepler science team announced the discovery of Kepler-452b, an exoplanet with many similarities to Earth. Its host star is just 10 percent larger than our Sun, the planet is 1.6 times the size of Earth, and the period of its orbit is only 5 percent longer than that of Earth. In addition, using the K2 observation technique, Kepler has uncovered strong evidence of a tiny, rocky object breaking apart as it spirals around a white dwarf star. This discovery validates a long-held theory that white dwarfs are capable of cannibalizing possible remnant planets that have survived within its solar system.

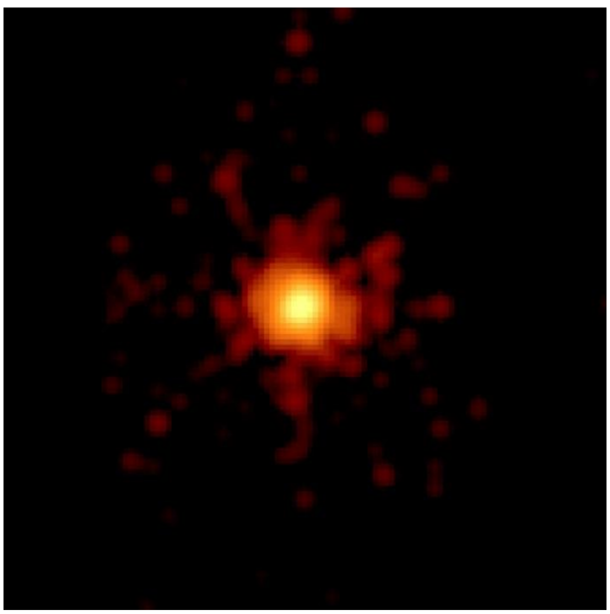
# Astrophysics Explorer

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Transiting Exoplanet Survey Satellite (TESS) | 80.1 | 73.5 | **87.0** | 27.9 | 9.1 | 2.5 | 0.0 |
| Other Missions and Data Analysis | 43.2 | -- | **42.0** | 63.1 | 146.9 | 201.1 | 186.2 |
| **Total Budget** | **123.3** | **--** | **129.0** | **91.0** | **156.0** | **203.5** | **186.2** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**A titanic burst of energy from a dying star 13 billion light years away has been spotted (center) from Earth.**

The Astrophysics Explorer program provides frequent flight opportunities for world-class astrophysics investigations using innovative and streamlined management approaches for spacecraft development and operations. The program is highly responsive to new knowledge, new technology, and updated scientific priorities by launching smaller missions that can be conceived and executed in a relatively short development cycle. NASA selects new missions based on an open competition of concepts solicited from the scientific community. The program emphasizes the accomplishments of missions under the control of the scientific research community within constrained mission life-cycle costs.

Medium-Class Explorers (MIDEX) missions cost up to $250 million in total, excluding launch services. Small Explorers (SMEX) may cost about half that total, excluding launch services. Explorer missions of opportunity (MO) have a total NASA cost of under $75 million and may be of several types. The most common type of MOs are those that will fly on a non-NASA space mission. NASA conducts these missions on a no-exchange-of-funds basis with the organization sponsoring the mission. Other possible types are new science missions using existing spacecraft and small complete missions. NASA intends to solicit proposals for MOs associated with each announcement of opportunity issued for MIDEX and SMEX investigations.

For more information on Explorer missions, see: http://explorers.gsfc.nasa.gov/missions.html.

# ASTROPHYSICS EXPLORER

## EXPLANATION OF MAJOR CHANGES IN FY 2017

The budget for future Astrophysics Explorer missions has been further refined from the FY 2016 request and still allows the program to meet the decadal survey-recommended cadence.

## ACHIEVEMENTS IN FY 2015

Japan installed the ASTRO-H project hardware on the spacecraft and completed integration and testing. The Neutron-star Interior Composition Explorer (NICER) project is nearing completion of the fabrication and integration of the instrument. The Transiting Exoplanet Survey Satellite (TESS) mission started Critical Design Review. In July 2015, NASA selected three SMEX proposals and two MO proposals for Phase A concept studies.

## WORK IN PROGRESS IN FY 2016

The ASTRO-H project is preparing for launch in February 2016. The NICER mission will complete instrument fabrication, integration, and test and prepare for launch. The TESS mission will continue its development of the instrument and spacecraft bus elements leading to its System Integration Review (SIR) in October 2016. The teams selected for the next SMEX and MO will begin their concept studies.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

ASTRO-H and NICER will have completed in-orbit checkout and will start the operational phase of data collection. TESS will begin phase D in November 2016. The selected SMEX and MO teams will complete their Phase A studies. NASA will begin the down selection process.

# ASTROPHYSICS EXPLORER

## Program Schedule

| Date | Significant Event |
|---|---|
| Aug 2015 | SMEX and Explorer MO KDP-A |
| Sep 2016 | AO announcement for MIDEX and MO opportunity to propose |
| Feb 2017 | Down select one SMEX and one MO mission for implementation |
| Aug 2017 | MIDEX and Explorer MO KDP-A |
| Feb 2019 | Down select one MIDEX and one MO mission for implementation |
| Sep 2019 | AO announcement of SMEX and MO opportunity to propose |
| Aug 2020 | SMEX and Explorer MO KDP-A |
| Sep 2021 | AO announcement for MIDEX and MO opportunity to propose |
| Feb 2022 | Down select one SMEX and one MO mission for implementation |
| Aug 2022 | MIDEX and Explorer MO KDP-A |

## Acquisition Strategy

NASA selects all Explorer missions through a competitive AO.

### INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Program Indepen-dent Review | SRB | Oct 2014 | Assess performance of program | Successful | Sep 2019 |

# TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

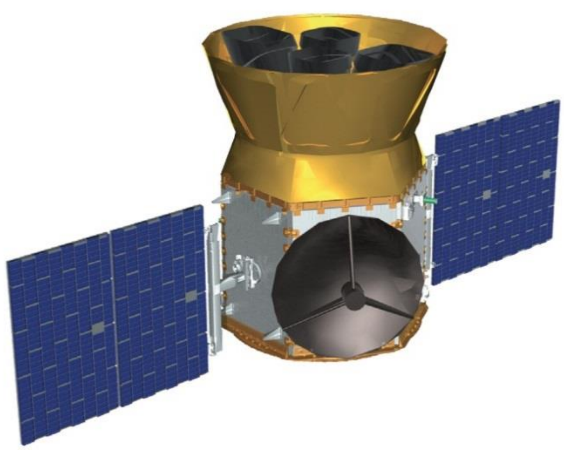
| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Prior | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 | BTC | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Formulation | 27.1 | 0.0 | 0.0 | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 27.1 |
| Development/Implementation | 44.5 | 80.1 | 73.5 | **83.2** | 15.1 | 0.0 | 0.0 | 0.0 | 0.0 | 296.4 |
| Operations/Close-out | 0.0 | 0.0 | 0.0 | **3.8** | 12.8 | 9.1 | 2.5 | 0.0 | 0.0 | 28.2 |
| **2016 MPAR LCC Estimate** | **71.6** | **80.1** | **73.5** | **87.0** | **27.9** | **9.1** | **2.5** | **0.0** | **0.0** | **351.7** |
| **Total Budget** | **71.6** | **80.1** | **73.5** | **87.0** | **27.9** | **9.1** | **2.5** | **0.0** | **0.0** | **351.7** |
| Change from FY 2016 | | | | **13.5** | | | | | | |
| Percentage change from FY 2016 | | | | **18.4%** | | | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**The TESS mission will detect small planets with bright host stars in the solar neighborhood, so that other telescopes can perform detailed characterizations of the planets and their atmospheres.**

## PROJECT PURPOSE

The TESS mission objective is to survey bright nearby stars for transiting exoplanets over a three-year period, including two years of TESS observations, and an additional third year of follow-up ground-based observations. The TESS mission will use an array of wide-field cameras to perform an all-sky survey.

TESS will carry out the first space-borne all-sky exoplanet transit survey, covering 400 times as much sky as any previous mission, including Kepler. It may discover approximately 30 Earth sized planets, 200 Super-Earth sized planets, and 400 sub-Neptune sized planets around other stars in the solar neighborhood.

With TESS, it will be possible to study the masses, sizes, densities, and orbits of small exoplanets, including a sample of rocky worlds in the habitable zones of their host stars. TESS will provide prime targets for further characterization by the James Webb Space Telescope (Webb), as well as other future large ground-based and space-based telescopes.

# TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

| Formulation | Development | Operations |
|---|---|---|

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## PROJECT PARAMETERS

NASA will launch TESS into a high Earth elliptical orbit. TESS will make observations in the visible and infrared spectrum, utilizing four telescopic charge-coupled device (CCD) cameras. TESS will obtain imagery from both northern and southern hemispheres of the sky. TESS will orbit the Earth every 13.7 days, and will downlink, via KA-band, the data it has collected over a period of approximately five hours each orbit. TESS will be a three axis-stabilized spacecraft using both momentum wheels and hydrazine thrusters.

## ACHIEVEMENTS IN FY 2015

TESS will start the Critical Design Review (CDR), which will continue into FY 2016.

## WORK IN PROGRESS IN FY 2016

TESS will continue its development of the instrument and spacecraft bus elements leading to its SIR in October 2016.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

TESS will begin Phase D after KDP-D planned in November 2016.

## SCHEDULE COMMITMENTS/KEY MILESTONES

NASA plans to launch TESS in June 2018 to begin a three-year prime mission.

| Milestone | Confirmation Baseline Date | FY 2017 PB Request |
|---|---|---|
| CDR | Apr 2015 | Dec 2015 |
| SIR | Oct 2016 | Oct 2016 |
| Start Phase D | Nov 2016 | Nov 2016 |
| ORR/FRR | Dec 2017 | Dec 2017 |
| LRD/IOC/IC | Jun 2018 | Jun 2018 |
| Start Phase E/FC/IC | Aug 2018 | Aug 2018 |
| End Prime Mission | Aug 2021 | Aug 2021 |

# TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

| Formulation | Development | Operations |
|---|---|---|

## Development Cost and Schedule

| Base Year | Base Year Develop-ment Cost Estimate ($M) | JCL (%) | Current Year | Current Year Develop-ment Cost Estimate ($M) | Cost Change (%) | Key Milestone | Base Year Milestone Data | Current Year Milestone Data | Milestone Change (mths) |
|---|---|---|---|---|---|---|---|---|---|
| 2015 | 323.2 | >70 | 2015 | 296.4 | -8 | LRD | Jun 2018 | Jun 2018 | 0 |

*Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.*

## Development Cost Details

This is the first report of development costs for this mission. The current year development cost estimate reflects savings from the award of the launch vehicle contract in December 2014.

| Element | Base Year Development Cost Estimate ($M) | Current Year Development Cost Estimate ($M) | Change from Base Year Estimate ($M) |
|---|---|---|---|
| **TOTAL:** | **323.2** | **296.4** | **-26.8** |
| Aircraft/Spacecraft | 43.0 | 50.6 | 7.6 |
| Payloads | 23.2 | 29.1 | 5.9 |
| Systems I&T | 3.7 | 3.7 | 0.0 |
| Launch Vehicle | 114.1 | 87.4 | -26.7 |
| Ground Systems | 16.7 | 12.9 | -3.8 |
| Science/Technology | 7.5 | 6.8 | -0.7 |
| Other Direct Project Costs | 115.0 | 105.9 | -9.1 |

# TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

| Formulation | Development | Operations |
|---|---|---|

## Project Management & Commitments

GSFC is responsible for Project Management.

| Element | Description | Provider Details | Change from Baseline |
|---|---|---|---|
| Instrument | Visible-IR telescopic CCDs detectors | Provider: Massachusetts Institute of Technology (MIT)<br>Lead Center: Lincoln Laboratories<br>Performing Center(s): N/A<br>Cost Share Partner(s): N/A | None |
| Spacecraft Bus | LEO Star three-axis stabilized spacecraft bus | Provider: Orbital ATK<br>Lead Center: N/A<br>Performing Center(s): N/A<br>Cost Share Partner(s): N/A | None |
| Launch Vehicle | Launch Vehicle | Provider: Space Exploration Technologies Corporation (SpaceX)<br>Lead Center: KSC<br>Performing Center(s): N/A<br>Cost Share Partner(s): N/A | None |

## Project Risks

| Risk Statement | Mitigation |
|---|---|
| If: Schedule reserves, as identified at the September 2014 Preliminary Design Review (PDR) remain tight,<br>Then: Instrument and spacecraft development may not be ready for subsequent observatory integration. | At the TESS KDP-C (October 2014), the TESS project announced the release of additional schedule reserves to selected aspects of both the TESS instrument and spacecraft in order to mitigate schedule concerns. Adequacy of schedule reserves will be reviewed after completion of CDR. |

## Acquisition Strategy

NASA selected the mission through a competitive Announcement of Opportunity.

# TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

| Formulation | Development | Operations |
|---|---|---|

## MAJOR CONTRACTS/AWARDS

None

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Spacecraft Bus | Orbital ATK | Dulles, VA |

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | SRB | Feb 2014 | System Requirements Review (SRR) | Successful | Preliminary Design Review (PDR) |
| Perform-ance | SRB | Sep 2014 | PDR | Successful | CDR |
| Perform-ance | SRB | Start Aug 2015 | CDR | On going | SIR |
| Perform-ance | SRB | Oct 2016 | SIR | TBD | Launch Readiness Review (LRR) |
| Perform-ance | SRB | 2018 | LRR | TBD | N/A |
| Perform-ance | SRB | 2018 | LRR | TBD | N/A |

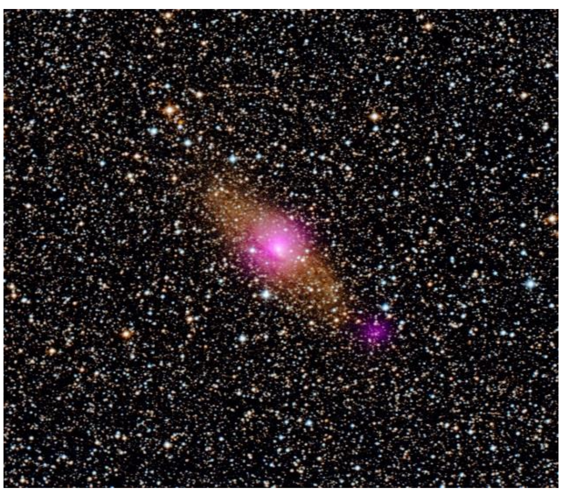
# OTHER MISSIONS AND DATA ANALYSIS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| ASTRO-H (SXS) | 11.3 | -- | **12.0** | 11.4 | 9.5 | 0.0 | 0.0 |
| Astrophysics Explorer Future Missions | 1.1 | -- | **16.8** | 42.7 | 132.2 | 192.6 | 178.5 |
| Astrophysics Explorer Program Management | 6.2 | -- | **9.8** | 7.7 | 5.1 | 8.5 | 7.7 |
| Neutron Star Interior Composition Explorer (NICER) | 11.7 | -- | **3.5** | 1.3 | 0.0 | 0.0 | 0.0 |
| SWIFT | 4.9 | -- | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| Suzaku (ASTRO-E II) | 0.6 | -- | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| Nuclear Spectroscopic Telescope Array (NuSTAR) | 7.4 | -- | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| **Total Budget** | **43.2** | **--** | **42.0** | **63.1** | **146.9** | **201.1** | **186.2** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**The NuSTAR took this X-ray image of two black holes in the Circinus Galaxy, which is 13 million light-years away. The two black holes, shown as magenta-colored objects superimposed on the optical galaxy image, consist of a supermassive black hole at the galaxy center and a smaller black hole on the galaxy edge..**

Astrophysics Explorer Other Missions and Data Analysis includes funding for small missions in formulation and development (ASTRO-H SXS, NICER), operating missions (NuSTAR, Swift, Suzaku), and funding for future mission selections and program management functions.

## Mission Planning and Other Projects

### ASTRO-H (SXS)

NASA is providing a High-Resolution Soft X-Ray Spectrometer (SXS) instrument to Japan for launch in 2016 onboard Japanese Aerospace Exploration Agency's (JAXA's) H-IIA rocket. The SXS instrument is a cryogenically cooled high-resolution X-ray spectrometer that will allow the most detailed studies of a wide range of astronomical systems from nearby stars to distant active galaxies. Using this unprecedented capability, the mission will conduct a number of fundamental studies, including tracing the growth history of the largest structures in the universe, obtaining insights into the behavior of material in extreme gravitational fields, determining the spin of black holes, probing shock acceleration structures in clusters of galaxies, and investigating the detailed physics of black hole jets. The Science Enhancement Option (SEO) supports mission planning, development and maintenance of data analysis software, development of a data processing pipeline, and

# OTHER MISSIONS AND DATA ANALYSIS

production and maintenance of ASTRO-H data archives. The SEO will also fund a Guest Observer (GO) Program, including proposal support and grant support.

### Recent Achievements

The Project integrated the SXS on the ASTRO-H spacecraft and successfully completed environmental testing and comprehensive performance testing. The spacecraft is now at the launch site.

## ASTROPHYSICS EXPLORER FUTURE MISSIONS

Astrophysics Explorer Future Missions funding supports future astrophysics Explorer missions and missions of opportunity through concept studies and selections.

## ASTROPHYSICS EXPLORER PROGRAM MANAGEMENT

Astrophysics Explorer program management provides programmatic, technical and business management of ongoing missions in formulation and development.

## NEUTRON STAR INTERIOR COMPOSITION EXPLORER (NICER)

The NICER instrument, to be located on the external logistics carrier of the ISS, will perform high time resolution and spectroscopic observations of neutron stars to uncover the nature and probe the physics of ultra-dense matter in the core of neutron stars. NICER will explore the exotic states of matter inside these stars where density and pressure are higher than in atomic nuclei. NICER will enable rotation-resolved spectroscopy of the thermal and non-thermal emissions of neutron stars in the soft X-ray band with unprecedented sensitivity, probing interior structure, the origins of dynamic phenomena, and the mechanisms that underlie the most powerful known cosmic particle accelerators.

### Recent Achievements

The project is nearing completion of the fabrication and integration of the instrument. Payload level testing will start in early 2016.

# Operating Missions

## SWIFT

Swift is a multi-wavelength space-based observatory that studies the position, brightness, and physical properties of gamma ray bursts. Swift is a MIDEX class mission that launched in 2004 and is now in extended mission operations.

### Recent Achievements

Swift continues to observe gamma-ray bursts at a rate of around 90 per year, as well as non-gamma-ray burst targets. Swift is uniquely equipped to make rapid-response observations to fast-breaking events throughout the universe. For example, when a star comes too close to a black hole, the intense gravity of the black hole results in tides that rip the star apart. In these events, called tidal disruptions, Swift has been monitoring stellar material falling towards the black hole, causing distinct X-ray flares that can last for a few years. Swift is detecting multiple rings centered upon flaring black holes that identify multiple reflecting dust layers between 4,000 and 7,000 light-years away from us. Regular monitoring of the rings, as the eruption continues, helps astronomers understand their nature. Swift is also discovering glitches in the once-thought regular clocks of spinning pulsars. Observations suggest that some pulsars' magnetic fields might be causing them to switch "on" and "off" intermittently. When they are on, intermittent pulsars' magnetic fields fill with plasma—a sea of charged particles, such as electrons and protons—and this generates radio waves. When pulsars switch off, the magnetic field lines change and let plasma escape.

## SUZAKU (ASTRO-E II)

Suzaku is Japan's fifth X-ray astronomy mission, which launched in July 2005 and is now in extended mission operations. The Institute of Space and Astronautical Science of JAXA (ISAS/JAXA) developed Suzaku in collaboration with U.S. (NASA and MIT) and Japanese institutions. NASA provides software to analyze Suzaku data and operates at a GO facility for U.S. observers.

### Recent Achievements

On June 1, 2015, the mission stopped communicating, due to a failure of the batteries onboard the spacecraft. ISAS/JAXA worked to recover the mission through the summer, but without success. On August 26, 2015, they announced the termination of the mission, and switched off its radio transceiver on September 2, 2015, thereby inactivating the mission. A closeout plan for the U.S. participation and the archiving of the data is under development. The funding needed to completely closeout the mission will use the entire FY 2016 request.

## NUCLEAR SPECTROSCOPIC TELESCOPE ARRAY (NUSTAR)

Launched in June 2012, the NuSTAR mission completed its prime mission in July 2014 and is now in extended mission operations. NuSTAR enables scientists to locate massive black holes in other galaxies, locate and examine the remnants of collapsed stars in our galaxy, observe selected gamma-ray sources, and observe any new supernovae in the local group of galaxies. NuSTAR's key science products are sensitive X-ray survey maps of the celestial sky. NuSTAR offers opportunities for a broad range of science investigations, ranging from probing cosmic ray origins and studying the extreme physics around collapsed stars to mapping micro flares on the surface of the Sun. NuSTAR performs follow-up observations to discoveries made by Chandra and Spitzer scientists. NuSTAR research teams collaborate with those using Fermi to make simultaneous observations. The NuSTAR mission implemented a GO facility for U.S. observers and will commence GOs in April 2015.

### Recent Achievements

NuSTAR continued its highly successful science program in 2015, providing invaluable new insights into the high-energy phenomena in the universe. NuSTAR observed the remains of SN1987A, which exploded just 28 years ago in the Large Magellanic Cloud. Utilizing its unique capability for detecting and mapping the emission from one of the elements produced in such explosions Titanium 44, the NuSTAR observations revealed that contrary to prior preconceptions, these events are spherically symmetric; this explosion was distinctly lopsided. The mission's novel imaging capability revealed that the ejected material flew outward in one direction while the compact core of the supernova, called a neutron star, sped off in the opposite direction. Together with the earlier observation of Cassiopeia A, which also showed evidence of an asymmetrical explosion, these new observations suggest that lopsidedness is at the very root of so-called “core-collapse” supernovas.

# JAMES WEBB SPACE TELESCOPE

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **645.4** | **620.0** | **569.4** | **533.7** | **304.6** | **197.2** | **149.8** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

## James Webb Space Telescope

# JAMES WEBB SPACE TELESCOPE

| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Prior | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 | BTC | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Formulation | 1800.1 | 0.0 | 0.0 | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1800.1 |
| Development/Implementation | 3545.2 | 645.4 | 620.0 | **569.4** | 533.7 | 227.6 | 47.5 | 0.0 | 0.0 | 6188.8 |
| Operations/Close-out | 0.0 | 0.0 | 0.0 | **0.0** | 0.0 | 77.0 | 149.8 | 149.8 | 460.0 | 836.6 |
| **2016 MPAR LCC Estimate** | **5345.3** | **645.4** | **620.0** | **569.4** | **533.7** | **304.6** | **197.2** | **149.8** | **460.0** | **8825.4** |
| **Total Budget** | **5273.2** | **645.4** | **620.0** | **569.4** | **533.7** | **304.6** | **197.2** | **149.8** | **460.0** | **8753.3** |
| Change from FY 2016 | | | | **-50.6** | | | | | | |
| Percentage change from FY 2016 | | | | **-8.2%** | | | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*


**Test fit of Webb flight telescope backplane structure and spacecraft bus structure.**

### PROJECT PURPOSE

The James Webb Space Telescope (Webb) is a large, space-based astronomical observatory. The mission is in many ways a successor to the Hubble Space Telescope, extending Hubble's discoveries by looking into the infrared spectrum. Webb will observe the highly red-shifted early universe and study relatively cool objects like protostars and protoplanetary disks, which emit infrared light strongly where dust obscures shorter wavelengths. With more light-collecting area than Hubble and with near- to mid-infrared-optimized instruments, Webb will observe objects farther away and further back in time.

The four main science goals are:

- Search for the first galaxies or luminous objects formed after the Big Bang;
- Determine how galaxies evolved from their formation until now;
- Observe the formation of stars from the first stages to the formation of planetary systems; and

# JAMES WEBB SPACE TELESCOPE

| Formulation | Development | Operations |
|---|---|---|

- Measure the physical and chemical properties of planetary systems and investigate the potential for life in those systems.

While Hubble greatly improved knowledge about distant objects, its infrared coverage is limited. Light from distant galaxies is redshifted out of the visible part of the spectrum into the infrared by the expansion of the universe. Webb will explore the poorly understood epoch when the first luminous objects in the universe came into being after the Big Bang.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## PROJECT PARAMETERS

Webb is an infrared-optimized observatory that will conduct imaging and spectrographic observations in the 0.6- to 28-micrometer wavelength range. Webb will be roughly 100 times more capable than Hubble, because its mirror is seven times larger, it will spend about twice as much time observing targets since the Earth will not be in the way, its detectors cover larger regions of the sky and are always on (i.e., can always be running in parallel), and its multi-object spectroscopic capabilities greatly expands the number of spectra per field.

The 6.5-meter primary mirror consists of 18 actively controlled segments. A multilayer sunshield the size of a tennis court passively cools the mirror, telescope optics, and instruments to about 40 Kelvin. Webb will launch in 2018 from Kourou, French Guiana on an Ariane 5 rocket, supplied by the European Space Agency (ESA). Webb will operate in deep space about one million miles from Earth.

Webb’s instruments include the Near Infrared Camera, Near Infrared Spectrograph, Mid-Infrared Instrument, and the Fine Guidance Sensor / Near Infrared Imager and Slitless Spectrograph.

The Near Infrared Camera takes images with a large field of view and high resolution, over the wavelength range of 0.6 to 5 micrometers. The Near Infrared Camera also aligns and focuses the optical telescope. The Near Infrared Camera detects light from the earliest stars and galaxies in the process of formation, stars in nearby galaxies, young stars in the Milky Way, and solar system Kuiper Belt objects. The Near Infrared Camera is equipped with coronagraphs, which allow astronomers to view dimmer objects near stars. With the coronagraphs, astronomers hope to determine the characteristics of planets orbiting nearby stars.

A spectrograph disperses light from an object into a spectrum. The atoms and molecules in the object imprint lines on its spectrum that uniquely fingerprint each chemical element present. Analyzing the spectrum of an object provides information on its physical properties, including temperature, mass, chemical composition, and motion.

The Near Infrared Spectrograph can obtain simultaneous spectra of more than 100 objects in a single exposure, over the wavelength range of 0.6 to 5 micrometers.

# JAMES WEBB SPACE TELESCOPE

| Formulation | Development | Operations |
|---|---|---|

The Mid-Infrared Instrument takes wide-field images and narrow-field spectra, over the wavelength range of 5 to 28 micrometers. The Mid-Infrared Instrument operates at about seven degrees Kelvin, which an onboard cooling system makes possible.

The Fine Guidance Sensor is a camera that provides fine pointing control and locks the telescope onto its target. The sensor operates over a wavelength range of 1 to 5 micrometers. The Near Infrared Imager and Slitless Spectrograph instrument provides unique imaging and spectroscopic modes to investigate the distant universe, as well as exoplanets.

For more information, go to http://www.jwst.nasa.gov.

## ACHIEVEMENTS IN FY 2015

In FY 2015, NASA made significant progress in the development, fabrication, and testing of many components of the Webb system. The project also successfully completed the following significant and technically challenging developments and tests:

- Installed new infrared detectors into the Fine Guidance Sensor / Near Infrared Imager and Slitless Spectrograph and Near Infrared Spectrograph instruments and new microshutters into the Near Infrared Spectrograph instrument;
- Delivered the Optical Telescope Element flight structure, including primary mirror backplane support structure, backplane support fixture, and wings to Goddard Space Flight Center (GSFC);
- Delivered the first flight sunshield membranes, continued the manufacture of the remaining sunshield layers, and continued the manufacture of the sunshield structure;
- Initiated the second optical ground support equipment test at Johnson Space Center (JSC); and
- Delivered the flight cryocooling compressor components to the Jet Propulsion Laboratory (JPL).

## WORK IN PROGRESS IN FY 2016

In FY 2016, the project plans to complete the following development and test efforts:

- Conduct the third and final cryogenic test of the Integrated Science Instrument Module, with all flight instruments and new detectors;
- Deliver the Integrated Science Instrument Module to GSFC for Optical Telescope element/Integrated Science instrument module integration;
- Complete the integration of flight primary mirror subassemblies onto the flight primary mirror backplane;
- Complete the acceptance testing of the cryocooler compressor assembly;
- Complete the spacecraft bus structure; and
- Complete the sunshield structure manufacture and test.

# JAMES WEBB SPACE TELESCOPE

| Formulation | Development | Operations |
|---|---|---|

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

The President's FY 2017 budget request provides the full level of funding required to keep Webb on schedule for a 2018 launch. In FY 2017, the project plans to:

- Deliver Optical Telescope element/Integrated Science to JSC for testing;
- Conduct Optical Telescope element/Integrated Science cryovacuum testing;
- Integrate the cryocooler compressor assembly into the spacecraft bus; and
- Deliver the flight solar array to the observatory for integration.

## SCHEDULE COMMITMENTS/KEY MILESTONES

NASA plans to launch Webb in October 2018 to begin a five-year prime mission. The following timeline shows the development agreement schedule per the rebaseline plan from September 2011.

| Milestone | Confirmation Baseline Date | FY 2017 PB Request |
|---|---|---|
| Key Decision Point (KDP)-C | Jul 2008 | Jul 2008 |
| Mission Critical Design Review (CDR) | Mar 2010 | Mar 2010 |
| Rebaseline/KDP-C Amendment | Sep 2011 | Sep 2011 |
| System Integration Review (SIR) | Jul 2017 | Jul 2017 |
| Launch | Oct 2018 | Oct 2018 |
| Begin Phase E | Apr 2019 | Apr 2019 |
| End of Prime Mission | Apr 2024 | Apr 2024 |

# Development Cost and Schedule

| Base Year | Base Year Develop-ment Cost Estimate ($M) | JCL (%) | Current Year | Current Year Develop-ment Cost Estimate ($M) | Cost Change (%) | Key Milestone | Base Year Milestone Data | Current Year Milestone Data | Milestone Change (mths) |
|---|---|---|---|---|---|---|---|---|---|
| 2012 | 6,197.9 | 66 | 2016 | 6,188.8 | -0.2 | LRD | Oct 2018 | Oct 2018 | 0 |

*Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs*

# JAMES WEBB SPACE TELESCOPE

| Formulation | Development | Operations |
|---|---|---|

*(confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.*

## Development Cost Details

| Element | Base Year Development Cost Estimate ($M) | Current Year Development Cost Estimate ($M) | Change from Base Year Estimate ($M) |
|---|---|---|---|
| **TOTAL:** | **6,197.9** | **6,188.8** | **-9.1** |
| Aircraft/Spacecraft | 2,955.0 | 3,212.2 | 257.2 |
| Payloads | 695.1 | 819.8 | 124.7 |
| Systems Integration & Test (I&T) | 288.4 | 382.9 | 94.5 |
| Launch Vehicle | 0.9 | 0.6 | -0.3 |
| Ground Systems | 652.3 | 575.4 | -76.9 |
| Science/Technology | 42.7 | 40.9 | -1.8 |
| Other Direct Project Costs | 1,563.5 | 1,156.9 | -406.6 |

# JAMES WEBB SPACE TELESCOPE

| Formulation | Development | Operations |
|---|---|---|

## Project Management & Commitments

NASA Headquarters is responsible for Webb program management. GSFC is responsible for Webb project management.

| Element | Description | Provider Details | Change from Baseline |
|---|---|---|---|
| Observatory | Includes OTE, spacecraft, sunshield, observatory assembly integration and testing, and commissioning. The observatory is designed for at least a five-year lifetime. Northrop Grumman Aerospace Systems (NGAS) has the lead for the OTE, sunshield, spacecraft bus, and selected assembly, integration, and testing activities. | Provider: NGAS and GSFC<br>Lead Center: GSFC<br>Performing Center(s): GSFC<br>Cost Share Partner(s): N/A | N/A |
| Mission management and system engineering | Includes management of all technical aspects of mission development, and system engineering of all components. | Provider: GSFC<br>Lead Center: GSFC<br>Performing Center(s): GSFC<br>Cost Share Partner(s): N/A | N/A |
| ISIM | Contains the science instruments and Fine Guidance Sensor. Provides structural, thermal, power, command and data handling resources to the science instruments and Fine Guidance Sensor. | Provider: GSFC<br>Lead Center: GSFC<br>Performing Center(s): GSFC<br>Cost Share Partner(s): N/A | N/A |
| NIRCam | Operates over the wavelength range of 0.6 to 5 micrometers, and optimized for finding first light sources. | Provider: University of Arizona, Lockheed Martin<br>Lead Center: GSFC<br>Performing Center(s): GSFC<br>Cost Share Partner(s): N/A | N/A |
| NIRSpec | Operates over the wavelength range of 0.6 to 5 micrometers with three observing modes. | Provider: ESA<br>Lead Center: ESA<br>Performing Center(s): N/A<br>Cost Share Partner(s): ESA | N/A |

# JAMES WEBB SPACE TELESCOPE

| Formulation | Development | Operations |
|---|---|---|

| Element | Description | Provider Details | Change from Baseline |
|---|---|---|---|
| MIRI | Operates over the wavelength range of 5 to 28 micrometers, providing imaging, coronagraphy, and spectroscopy. | Provider: ESA, University of Arizona, JPL<br>Lead Center: GSFC<br>Performing Center(s):<br>Cost Share Partner(s): ESA | N/A |
| Fine Guidance | Provides scientific target pointing information to the observatory's attitude control sub-system | Provider: Canadian Space Agency (CSA)<br>Lead Center: CSA<br>Performing Center(s): N/A<br>Cost Share Partner(s): CSA | N/A |
| Launch vehicle and launch operations | Ariane 5 | Provider: ESA<br>Lead Center: ESA<br>Performing Center(s): N/A<br>Cost Share Partner(s): ESA | N/A |
| Ground control system and science operations and control center | Includes mission operations and science operations center | Provider: Space Telescope Science Institute (STScI)<br>Lead Center: GSFC<br>Performing Center(s): N/A<br>Cost Share Partner(s): N/A | Ground control system and science operations and control center |

## Project Risks

| Risk Statement | Mitigation |
|---|---|
| If: Sunshield flight layer delivery changes to a later date<br>Then: This may delay sunshield or observatory integration and test, adding risk to achieving the October 2018 launch. | The Project will work with the NGAS team to establish acceptable schedules for sunshield flight layer delivery, and to adapt sunshield and observatory integration and test schedules based on those delivery schedules, without delaying launch. |

# JAMES WEBB SPACE TELESCOPE

| Formulation | Development | Operations |
|---|---|---|

## Acquisition Strategy

The project has awarded all major contracts.

### MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Science and Operations Center | STScI | Baltimore, MD |
| NIRCam | University of Arizona;<br>Lockheed Martin | Tucson, AZ<br>Palo Alto, CA |
| Observatory | NGAS<br>Ball Aerospace<br>ITT/Exelis<br>Alliant Techsystems | Redondo Beach, CA<br>Boulder, CO<br>Rochester, NY<br>Edina, MN |
| Near Infrared Detectors | Teledyne Imaging Systems | Camarillo, CA |

### INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | Strategic Review Board (SRB) | Apr 2010 | CDR | Determined mission design is mature and recommended a more in-depth review of the integration and testing plan | N/A |
| Quality | Test Assessment Team | Aug 2010 | Evaluate plans for integration and testing. See the full report at http://www.jwst.nasa.gov/publications.html | The team recommended several changes to the test plan | N/A |
| Other | Independent Comprehensive Review Panel | Oct 2010 | Determine the causes of cost growth and schedule delay on Webb, and estimate the launch date and budget, including adequate reserves | The report made 22 recommendations, covering several areas of management and performance | N/A |

# JAMES WEBB SPACE TELESCOPE

| Formulation | Development | Operations |
|---|---|---|

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Other | The Aerospace Corporation | Apr 2011 | Analysis of alternatives | Determined that Webb design was still the best value to achieve the primary scientific objectives of the mission | N/A |
| Other | SRB | May 2011 | Review technical, cost, and schedule plans | The SRB proposed rebaselined project technical, cost, and schedule plans and made recommendations to the Agency | N/A |
| Perform-ance | NASA Headquarters Office of Evaluation | Jun 2012 | Replan assessment review | A review assessed progress against replan | N/A |
| Perform-ance | SRB | N/A | Optical Telescope element/Integrated Science System Integration Review | | May 2016 |
| Perform-ance | SRB | N/A | Optical Telescope element/Integrated Science Pre-Environmental Review | | Jun 2016 |
| Perform-ance | SRB | N/A | Spacecraft Element Readiness Review | | Apr 2016 |
| Perform-ance | SRB | N/A | SIR | | Jul 2017 |
| Perform-ance | SRB | N/A | FRR | | Sep 2018 |

# HELIOPHYSICS

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Heliophysics Research | 192.0 | -- | **180.1** | 192.0 | 210.0 | 215.9 | 214.2 |
| Living with a Star | 263.5 | -- | **374.2** | 398.7 | 244.6 | 135.8 | 127.3 |
| Solar Terrestrial Probes | 70.6 | -- | **39.8** | 38.8 | 127.3 | 179.4 | 198.4 |
| Heliophysics Explorer Program | 110.0 | -- | **104.6** | 54.5 | 116.3 | 183.8 | 184.0 |
| **Total Budget** | **636.1** | **--** | **698.7** | **684.0** | **698.3** | **714.8** | **723.9** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

## Heliophysics

# HELIOPHYSICS RESEARCH

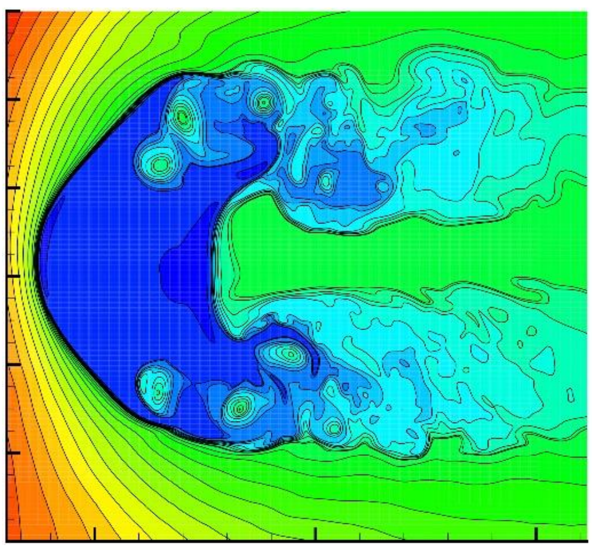
## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Heliophysics Research and Analysis | 34.1 | -- | **38.9** | 48.9 | 53.9 | 53.9 | 53.9 |
| Sounding Rockets | 66.2 | -- | **53.3** | 59.0 | 61.1 | 63.1 | 63.1 |
| Research Range | 21.3 | -- | **21.7** | 21.7 | 25.1 | 25.1 | 25.2 |
| Other Missions and Data Analysis | 70.4 | -- | **66.2** | 62.4 | 70.0 | 73.7 | 71.9 |
| **Total Budget** | **192.0** | **--** | **180.1** | **192.0** | **210.0** | **215.9** | **214.2** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*



**For decades, scientists have visualized the heliosphere as shaped like a comet, with a very long tail extending some 464 billion miles. New NASA-funded research now suggests that the heliosphere is actually dominated by two giant jets of material shooting backwards over the north and south poles of the sun, which are confined by the interaction of the sun's magnetic field with the interstellar magnetic field. These curve around in two relatively short tails toward the back. The end result is a heliosphere that looks a lot more like a crescent moon than a comet.**

Heliophysics seeks to understand the Sun and its interactions with Earth and the solar system, including space weather. The goal of Heliophysics is to understand the Sun, heliosphere, and planetary environments as a single, connected system and to answer these fundamental questions about this system's behavior.

- What causes the Sun to vary?
- How do Earth and the heliosphere respond to the Sun's changes?
- What are the impacts on humanity?

Heliophysics Research improves our understanding of fundamental physical processes throughout the solar system, and enables us to understand how the Sun, as the major driver of the energy throughout the solar system, affects our technological society. The scope of heliophysics ranges from the Sun's interior to Earth's upper atmosphere and beyond, through interplanetary space to the end of the region of the Sun's influence, far beyond the outer planets. Heliophysics incorporates studies of the interconnected elements in a single system that produces dynamic space weather and evolves in response to solar, planetary, and interstellar conditions.

# HELIOPHYSICS RESEARCH

For more information, go to http://science.nasa.gov/about-us/smd-programs/heliophysics-research.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Mandatory Budget Authority | -- | -- | 15.0 | -- | -- | -- | -- |

Heliophysics Research is supported in part with mandatory funding. The mandatory investment includes $5 million for Research and Analysis, in support of the National Academies decadal survey recommendation to augment the current research program, and $10 million for CubeSats, tripling the amount available to achieve science goals with lower-cost, small satellites.

## ACHIEVEMENTS IN FY 2015

Scientists have long been puzzled about why the corona, the upper solar atmosphere, is over one thousand times hotter than the surface of the Sun. Data from several missions of NASA's Heliophysics System Observatory have now provided evidence for two physical mechanisms to explain why the corona is so hot. Scientists combined data from NASA's Interface Region Imaging Spectrograph (IRIS) and the joint Japanese Aerospace Exploration Agency (JAXA)-NASA Hinode satellite to show how magnetic waves carry energy from the surface to solar filaments, suspended in the corona by magnetic fields. Here the wave motions transform into heat, a process in which wave interference heats the gas from 20,000 to at least 200,000 degrees Celsius. In another study of hotter regions on the Sun, scientists used data from IRIS and NASA's Solar Dynamics Observatory (SDO) to reveal evidence for an alternative heating mechanism in which small events called nanoflares release magnetic energy. Comparisons between numerical models and high-resolution observations of these nanoflares show how particles accelerate to very high energies and speeds, which heat small pockets of gas to temperatures of millions of degrees and propel the gas upward into the corona. These new results show that coronal heating is more complex than originally thought, with the dominant mechanisms likely dependent on local conditions. The results enable a deeper understanding of the fundamental physical processes that underlie Earth's space environment.

The Sun constantly emits a supersonic stream of electrified and magnetized gas called the solar wind. When it reaches Earth, the planet's strong magnetic field, the magnetosphere, deflects most of the wind. The solar wind can enter near-Earth space if the solar magnetic field connects with Earth's magnetic field. Scientists have made key discoveries regarding two entry mechanisms. Kelvin-Helmholtz (KH) waves form as the solar wind flows around Earth's magnetosphere, allowing a mixing of solar wind plasma across this surface. Previously, scientists thought KH waves only appeared under specialized conditions. To determine when and where KH waves occur in near-Earth space, scientists used data from two NASA Heliophysics spacecraft: the Advanced Composition Explorer (ACE) and the Time History of Events and Macroscale Interactions during Substorms (THEMIS). Similarly, when the solar magnetic field simultaneously connects to Earth's magnetic field in two places it captures the solar wind near the "nose" of the magnetosphere. Researchers used data from the joint European Space Agency (ESA)-NASA Cluster spacecraft to demonstrate that such double reconnection events occur regularly when the solar magnetic field has a certain orientation. These two independent discoveries show that the solar wind regularly crosses the magnetosphere boundary and enters near-Earth space.

Gravity waves, waves in the atmosphere similar to ocean tides, play an important part in the dynamics of Earth's atmosphere. The waves transfer energy and momentum over large distances and drive winds in the upper mesosphere. For the first time, NASA-funded grants contributed to a new whole-atmosphere circulation model that resolves gravity waves down to the tens of kilometers level. The new simulation revealed the planetary-scale extent of a group of gravity waves about 60 miles above the Earth's surface, directly attributed to a tropical cyclone. The model shows the increasing dominance of gravity waves at higher altitudes.

## WORK IN PROGRESS IN FY 2016

In 2016, NASA will continue its recently restructured portfolio of competed research programs, a first step in implementing the Diversify, Realize, Integrate, Venture, Educate (DRIVE) initiative, outlined in the National Academies' 2013 Decadal Survey for Solar and Space Physics. The 2015 Research Opportunities in Space and Earth Sciences NASA Research Announcement (ROSES NRA), which solicits proposals for FY 2016 funding, reflects the restructured portfolio.

Heliophysics continues implementation of CubeSats on behalf of the Science Mission Directorate (SMD). The project funded three new CubeSat missions, now including one Astrophysics mission and two Planetary Science missions. Heliophysics is funding a collaborative effort with NASA's Human Exploration and Operations Mission Directorate (HEOMD) to expand the scope of one previously funded CubeSat mission to enable interplanetary flight on the Exploration Mission (EM)-1 mission, the first flight using the Space Launch System (SLS). The EM-1 CubeSat began implementation in FY 2015, preparing for possible launch in FY 2018.

NASA more clearly separated the solicitations of ROSES-15: Supporting Research and Guest Investigator program elements. The Supporting Research solicitation requires synergy of data analysis with key enhancement from numerical simulations, theory, or modeling. The Guest Investigator solicitation requires a focus on current Heliophysics operating missions to take full advantage of critical new observations of the entire Heliophysics System Observatory missions. NASA will announce awards for these ROSES elements in early calendar year 2016.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

In FY 2017, the Heliophysics Research program anticipates significant science results from the Magnetospheric Multiscale (MMS) mission, as well as results from 18 active space missions (28 individual spacecraft) that comprise the remainder of the Heliophysics System Observatory. These include ACE; Aeronomy of Ice in the Mesosphere (AIM); Geotail, Hinode, Interstellar Boundary Explorer (IBEX); IRIS, MMS (four spacecraft); Ramaty High Energy Solar Spectroscopic Imager (RHESSI); Solar Dynamics Observatory (SDO); Space Environment Testbeds (SET, planned October 2016 launch); Solar and Heliospheric Observatory (SOHO); Solar Terrestrial Relations Observatory (STEREO, two spacecraft); Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED); THEMIS (five spacecraft); Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS, two spacecraft); Van Allen Probes (two spacecraft); Voyager (two spacecraft); and Wind. The anticipated awards of small research investigations will continue the science advancements.

# HELIOPHYSICS RESEARCH

In addition to operating mission data, the budget request supports a flight program of 16 to 20 sounding rocket flights, with one to two remote campaign deployments in Poker Flats, Alaska; Norway; and potentially Australia.

## Program Elements

### RESEARCH RANGE

The Research Range Services (RRS) project provides operations support, maintenance, and engineering for the Wallops Launch Range and instrumentation. The range and instrumentation support suborbital, orbital, and aircraft missions conducted on behalf of NASA and the Department of Defense at the Wallops Flight Facility and at remote sites around the world. New work includes support for NASA technology missions, unmanned aerial vehicle flights, and commercial launch and flight projects.

The range instrumentation includes meteorological, telemetry, radar, command, launch and range control centers, and optical systems. RRS mobile assets provide range services at other ranges and remote locations around the world.

### SOUNDING ROCKETS

The Sounding Rockets Project supports the NASA strategic vision and goals for Earth Science, Heliophysics, Planetary Science, and Astrophysics. The missions flown annually by the project provide researchers with unparalleled opportunities to build, test, and fly new instrument and sensor design concepts while simultaneously conducting world-class scientific research. Coupled with a hands-on approach to instrument design, integration, and flight, the short mission life cycle helps ensure that the next generation of space scientists receives the training and experience necessary to move on to NASA's larger, more complex space science missions.

With the capability to fly higher than many low-Earth orbiting satellites and the ability to launch on demand, sounding rockets often offer the only means to study specific scientific phenomena of interest to many researchers. Unlike instruments on board most orbital spacecraft or in ground-based observatories, sounding rockets can place instruments directly into regions where and when the science is occurring to enable direct, in-situ measurements. The mobile nature of the project enables researchers to conduct missions from strategic vantage points worldwide. Telescopes and spectrometers to study solar and astrophysics phenomena fly on sounding rockets to collect unique science data and test prototype instruments for future satellite missions.

### HELIOPHYSICS RESEARCH AND ANALYSIS

This project supports basic research, solicited through NASA's annual ROSES announcements. These research activities address our understanding of the Sun and planetary space environments, including the origin, evolution, and interactions of space plasmas and electromagnetic fields throughout the heliosphere and in connection with the galaxy. Understanding the origin and nature of solar activity and its interaction with the space environment of the Earth is a particular focus. This project supports Heliophysics Grand Challenge Research (theory) (GCR), Low Cost Access to Space investigations, instrument development, and necessary research directly linked to Heliophysics science questions.

# HELIOPHYSICS RESEARCH

Heliophysics GCR investigations are the foundation of the Heliophysics Research and Analysis project. They lead the way to new understanding of previous investigations and drive science concepts for future missions. The Heliophysics GCR element supports large Principal Investigator-proposed team efforts that require a critical mass of expertise to make significant progress in understanding complex physical processes with broad importance.

Low Cost Access to Space investigations use spaceflight of experimental instrumentation to achieve scientific goals and proof-test new technology that may ultimately find application in larger or strategic Heliophysics space missions. These investigations may use a range of flight opportunities, including suborbital rockets, suborbital reusable launch vehicles, ISS payloads, CubeSats, and balloon flights.

Instrument development investigations develop technology with promise for use in scientific investigations on future Heliophysics science missions. These investigations may include the development of laboratory instrument prototypes, but not of flight hardware. The goal is to define and develop scientific instruments and/or components of such instruments to the point where complete instruments are ready for future Announcements of Opportunity (AOs) without significant additional technology development.

Supporting research investigations guide the direction and content of future science missions. They employ a variety of fundamental research techniques (e.g., theory, numerical simulation, and modeling), analysis, and interpretation of space data, development of new measurement concepts, and laboratory measurements of relevant atomic, plasma and nuclear parameters.

## Program Schedule

NASA implements the Heliophysics Research program via a competitively selected process. NASA releases research solicitations each year through the ROSES NRA, aiming to initiate research for about one-third of the program, given the selected investigations are typically three-year awards. Therefore, NASA will allocate FY 2016 funds to ROSES-2015, ROSES-2014, and ROSES-2013 selections.

| Date | Significant Event |
|---|---|
| Q1, Q2 FY 2016 | ROSES-2015 selections: Oct 2015–Mar 2016 |
| Q2 FY 2016 | ROSES-2016 solicitation: Feb 2016 |
| Q3/Q4 FY 2016 | Review of proposals submitted to Heliophysics ROSES-2016 elements |

# HELIOPHYSICS RESEARCH

## Program Management & Commitments

| Program Element | Provider |
|---|---|
| Research and Analysis | Provider: HQ<br>Lead Center: HQ<br>Performing Centers: Goddard Space Flight Center (GSFC), Marshall Space Flight Center (MSFC), Jet Propulsion Laboratory (JPL), Langley Research Center (LaRC), Johnson Space Center (JSC)<br>Cost Share Partners: None |
| Sounding Rockets and Research Range | Provider: GSFC<br>Lead Center: HQ<br>Performing Center: GSFC<br>Cost Share Partners: None |
| Heliophysics Operating Missions | Provider: GSFC, JPL, MSFC<br>Lead Center: HQ<br>Performing Center: GSFC, JPL, MSFC<br>Cost Share Partners: None |

## Acquisition Strategy

NASA fully and openly competes all new acquisitions. Proposals are peer-reviewed and selected from the annual ROSES announcement. Universities, government research laboratories, and industry partners throughout the United States participate in research projects. NASA previously selected the Heliophysics operating missions and instrument teams via NASA AOs. NASA evaluates the allocation of funding among the operating missions bi-annually through the Heliophysics Senior Review process.

### MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Sounding Rocket Operations | Orbital ATK, Dulles, VA | Various |

# HELIOPHYSICS RESEARCH

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Quality | Mission Senior Review Panel | Apr 2015 | A comparative evaluation of Heliophysics operating missions | The report, released in June 2015, assessed missions individually, and as part of a system observatory | Apr 2017 |

# OTHER MISSIONS AND DATA ANALYSIS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Science Planning and Research Support | 6.5 | -- | **6.7** | 6.8 | 6.8 | 6.8 | 6.8 |
| Directed Research & Technology | 18.4 | -- | **3.9** | 5.4 | 3.2 | 6.3 | 4.5 |
| CubeSat | 6.5 | -- | **15.0** | 5.0 | 5.0 | 5.0 | 5.0 |
| Solar Data Center | 0.9 | -- | **1.1** | 1.2 | 1.3 | 1.1 | 1.2 |
| Data & Modeling Services | 2.0 | -- | **2.8** | 2.7 | 3.0 | 3.0 | 3.0 |
| Space Physics Data Archive | 2.0 | -- | **2.3** | 2.3 | 2.3 | 2.3 | 2.3 |
| Guest Investigator Program | 10.8 | -- | **10.3** | 15.2 | 24.3 | 24.7 | 24.7 |
| Community Coordinated Modeling Center | 2.2 | -- | **2.2** | 2.2 | 2.3 | 2.4 | 2.4 |
| Space Science Mission Ops Services | 11.3 | -- | **11.5** | 11.5 | 11.6 | 11.9 | 11.9 |
| Voyager | 5.5 | -- | **5.6** | 5.5 | 5.6 | 5.5 | 5.5 |
| SOHO | 2.2 | -- | **2.3** | 2.2 | 2.3 | 2.3 | 2.3 |
| WIND | 1.8 | -- | **2.2** | 2.2 | 2.2 | 2.2 | 2.2 |
| GEOTAIL | 0.2 | -- | **0.2** | 0.2 | 0.2 | 0.2 | 0.2 |
| CLUSTER-II | 0.2 | -- | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| **Total Budget** | **70.4** | **--** | **66.2** | **62.4** | **70.0** | **73.7** | **71.9** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

# OTHER MISSIONS AND DATA ANALYSIS

**The interaction of solar winds and Earth's atmosphere produces northern lights, or auroras. This interaction produces many questions regarding the role it plays in Earth's meteorological processes and the impact on the planet's atmosphere. To help answer some of these questions, five NASA suborbital sounding rockets carrying university-developed experiments were launched into auroras between 2 and 6 a.m. EST, January 13 through 27, 2015, from the Poker Flat Research Range in Alaska.**

NASA accumulates, archives, and distributes data collected by the Heliophysics System Observatory, a fleet of operating spacecraft. Combining the measurements from all of these observing platforms enables interdisciplinary, connected systems science across the vast spatial scales of our solar system. This collective asset enables the data, expertise, and research results to contribute directly to fundamental research on solar and space plasma physics and to the national goal of real-time space weather prediction. NASA teams support day-to-day mission operations for NASA spacecraft and data analysis to advance the state of space science and space weather modeling. NASA conducts science community-based projects to evaluate research models containing space weather information that is of value to industry and government agencies. Heliophysics data centers archive and distribute the science data from operating missions in the Living With a Star (LWS), Solar Terrestrial Probes (STP), Research, and Explorer programs.

## Mission Planning and Other Projects

### SCIENCE PLANNING AND RESEARCH SUPPORT

This project supports NASA's participation in proposal peer review panels, decadal surveys, and National Academies studies.

### DIRECTED RESEARCH AND TECHNOLOGY

This project funds the civil service staff that work on emerging flight projects, instruments, and research.

### CUBESAT

Heliophysics implemented a CubeSat project in response to the 2013 Decadal Survey DRIVE initiative recommendation. The aim of the project is to explore the viability of this lower-cost option for enabling scientific discovery across the various themes and disciplines within SMD.

CubeSats are small spacecraft, built to a standardized form-factor of size and mass, which can launch as secondary or ride-share payloads. With development costs between $3 million and $6 million per

# OTHER MISSIONS AND DATA ANALYSIS

investigation and with rapid development cycles, CubeSats can provide frequent science and technology flight opportunities.

All SMD science disciplines allow proposals to build and fly instruments on CubeSats. This approach is similar to the traditional NASA suborbital programs that use sounding rockets, balloons, and aircraft, but extends the range of opportunities. CubeSats have significant potential to leverage exploratory and systematic science observations at minimal additional cost. The CubeSat project is initiating an exciting re-evaluation in many aspects of the NASA space research enterprise and thus provides conceptual level benefits well beyond the individual missions themselves. SMD is also working closely with STMD to maximize the benefit from STMD's CubeSat efforts.

## SOLAR DATA CENTER

The Solar Data Center provides mission and instrument expertise to enable high-quality analysis of solar physics mission data. It provides leadership for community-based, distributed development efforts to facilitate identifying and accessing solar physics data, including ground-based coordinated observations residing in the Virtual Solar Observatory. The center also provides a repository for software used to analyze these data. The Virtual Solar Observatory is a software system that links together distributed archives of solar data into a unified whole, along with data search and analysis tools.

## DATA AND MODELING SERVICES

This project supports missions in extended operations and missions transitioning to decommissioning to prepare their data holdings for long-term archival curation. This project also provides for the creation of higher-level data products, which are of significant use to the science community and not funded during the prime mission. Higher-level data products are data that combine results of multiple missions and/or instruments. Elements of this project are competed through the annual ROSES competitive announcement.

## SPACE PHYSICS DATA ARCHIVE

The Space Physics Data Facility (SPDF) ensures long-term data preservation and online access to non-solar heliophysics science data. It operates key infrastructure components for the Heliophysics Data Environment, including inventory and web service interfaces to systems and data. It also provides unique enabling science data services.

## GUEST INVESTIGATOR PROGRAM

The Guest Investigator program maximizes the return from currently operating Heliophysics missions by supporting studies consistent with the science goals of these missions and those expressed in the 2013 decadal survey and 2014 SMD Science Plan. These competitive research investigations use data from multiple spacecraft, as appropriate. Investigations addressing global system science are strongly encouraged, as Heliophysics is, by its nature, the investigation of a large-scale, complex, connected system.

# OTHER MISSIONS AND DATA ANALYSIS

## COMMUNITY COORDINATED MODELING CENTER (CCMC)

The Community Coordinated Modeling Center (CCMC) is a multi-agency partnership to enable and perform the research and development for next-generation heliophysics and space weather models. The center provides the United States and international research community access to simulations to enable "runs on demand," using models to study space weather events in near-real time. This allows the comparison of observational data and model parameters during or shortly after solar activity, thereby improving accuracy of the models.

## SPACE SCIENCE MISSION OPERATIONS SERVICES

Space Science Mission Operations Services manages the on-orbit operations of GSFC Space Science missions. Services include consistent processes and infrastructure for missions operated at GSFC, Johns Hopkins University Applied Physics Laboratory (JHU-APL), Orbital-Alliant Techsystems (Orbital-ATK), Pennsylvania State University, and University of California at Berkeley. Space Science Mission Operations Services also sustains an operational infrastructure for current and future missions.

# Operating Missions

## VOYAGER

The Voyager Interstellar Mission is exploring the interaction of the heliosphere and the local interstellar medium. Voyager 1 is making the first in-situ observations of the region outside the heliosphere from about 130 astronomical units (AU), or 130 times Earth's distance from the Sun, and is traveling at a speed of 3.6 AU per year. Voyager 2 is about 106 AU from the Sun and traveling at a speed of about 3.3 AU per year. Spacecraft power should be adequate for currently operating instruments through 2020.

### Recent Achievements

Voyager 1 has entered a new frontier: the local interstellar medium. In this region, the Sun's influence is no longer dominant and the spacecraft is seeing the full spectrum of low energy galactic cosmic rays. The spectra of these energetic particles are providing critical insights about the origin of these particles as well as the nature of the interstellar medium between Voyager 1 and their source. Voyager 1 also measures interstellar magnetic fields, plasmas, and particles, but still observes disturbances produced by the Sun and transmitted through the heliopause. These disturbances produce vibrations that allow the spacecraft to measure plasma density in the local interstellar medium. The strength of these disturbances is providing information about the nature of the local interstellar medium between Voyager 1 and the source of these disturbances, the Sun. Voyager 1 also measures the strength and small-scale fluctuations of the interstellar magnetic field and sets limits on turbulence in the local interstellar medium. The position and shape of the IBEX energetic neutral atom ribbon, a region of the sky observed by IBEX to have strong emission of energetic neutral atoms, strongly depend on the orientation, strength, and fluctuations of the interstellar magnetic field. These results have helped answer questions about the origin of the IBEX ribbon while also creating new ones about why there is so little turbulence in the local interstellar medium.

# OTHER MISSIONS AND DATA ANALYSIS

## SOLAR AND HELIOSPHERIC OBSERVATORY (SOHO)

SOHO combines remote sensing of the Sun and the consequences of solar activity with measurements of the space environment near the L1 Lagrangian point, located about one million miles from Earth toward the Sun. SOHO is the main source of near-real-time solar data for space weather predictions. The Large Angle and Spectrometric Coronagraph on SOHO is a unique instrument on the Sun-Earth line that is important to the Nation's space weather architecture. This instrument helps scientists understand coronal mass ejections (CMEs), which are large bursts of plasma from the Sun that can collide with Earth's magnetosphere and cause disruptions to technological infrastructure in space and on the ground. SOHO also enables studies of CMEs and their effect on interplanetary space.

### Recent Achievements

SOHO reached a milestone on December 2, 2015, when the spacecraft turned 20 years old. SOHO, a joint mission of the European Space Agency (ESA) and NASA, has been a dependable solar watchdog all the while, providing the only Earth-Sun line coronagraph images of solar storms. Citizen scientists have used SOHO to discover more than 3,000 comets, a capability no one anticipated before launch. CMEs drive most of the space weather effects in the inner heliosphere. In particular, effective forecasting of potential space weather effects here on Earth requires knowledge of speed and direction of propagation of CMEs. In the past, the assumption has always been that CMEs that appear as "halos" surrounding the Sun travel directly toward or away from the observer.

Recent work using data from SOHO and the two STEREO spacecraft, however, has shown that such halos are in fact evidence of the shock wave generated by the CME. The shock waves can in some instances travel around the entire Sun, and interpreting the halos alone as evidence of propagation direction can be highly misleading. Fortunately, with views from both near the Earth (SOHO) and at a significant angular separation from that view (from the well-positioned STEREO spacecraft), researchers can derive accurate CME propagation directions for purposes of forecasting.

## WIND

The Wind spacecraft studies the solar wind and its impact on the near-Earth environment. It addresses wave-particle interaction processes in the space environment, evolution of solar activity in the heliosphere, and geomagnetic impact of solar activity. Wind performs in-situ studies using unique capabilities, such as three-dimensional particle distributions over a wide range of energies, and delivers higher time resolution than available from any other mission. Wind provides critical measurements of the solar wind and space weather events. Correlating those with measurements from the upcoming Solar Probe Plus (SPP) and Solar Orbiter Collaboration (SOC) missions will improve our understanding of these events as they move out from the Sun. These multi-spacecraft measurements constrain models of space weather events and improve their predictive capabilities.

### Recent Achievements

Wind continues to provide unique, robust, high-resolution solar wind measurements that have resulted in over 500 refereed publications in the last two years.

# OTHER MISSIONS AND DATA ANALYSIS

## GEOTAIL

Geotail enables scientists to assess data on the interaction of the solar wind and magnetosphere. July 24, 2015 marked the 23rd anniversary of the launch of Geotail. Its instruments continue to function, sending back crucial information about how auroras form, how energy from the Sun funnels through near- Earth space, and the ways in which magnetic field lines move and rebound, creating explosive bursts that rearrange the very shape of our magnetic environment. The Geotail mission is a collaborative project undertaken by the Japanese Institute of Space and Astronautical Science and NASA.

# LIVING WITH A STAR

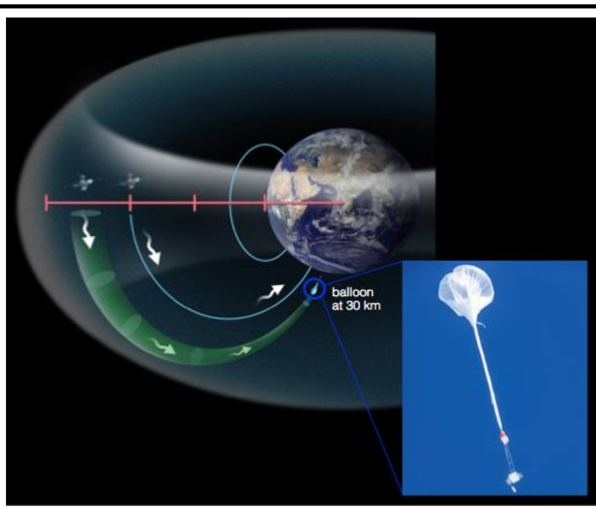
## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | FY 2018 | Notional FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Solar Probe Plus (SPP) | 193.7 | 238.6 | **232.5** | 289.7 | 100.4 | 30.6 | 22.1 |
| Solar Orbiter Collaboration (SOC) | 20.5 | 49.8 | **80.7** | 51.4 | 66.3 | 2.3 | 2.4 |
| Other Missions and Data Analysis | 49.4 | -- | **61.0** | 57.7 | 77.9 | 103.0 | 102.8 |
| **Total Budget** | **263.5** | **--** | **374.2** | **398.7** | **244.6** | **135.8** | **127.3** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*




**During solar storms, destructive electrons in Earth's radiation belts have been known to vanish – only to return a few hours later. Some electrons precipitate into our upper atmosphere, harmlessly depositing their energy high above our planet's surface. Since 2013, the BARREL team has launched over 40 research balloons to work in conjunction with NASA's Van Allen Probes that measure the electrons from above. BARREL balloons observe the electron rainfall by detecting the telltale glow of X-rays, which are the by-product of electrons striking atoms and molecules in the upper atmosphere.**

The LWS program targets specific aspects of the Sun-Earth-planetary system that affect life and society. LWS provides a predictive understanding of the Sun-Earth system, linkages among the interconnected systems, and, specifically, space weather conditions at Earth and the interplanetary medium. Measurements and research from LWS missions may help prevent damage to spacecraft, communications and navigation systems, and power grids. LWS products improve our understanding of ionizing radiation, which has human health implications on the ISS and high-altitude aircraft flight, as well as operations of future space exploration with and without human presence. LWS products improve the definition of solar radiation for global climate change, surface warming, and ozone depletion and recovery.

For more information, go to http://science.nasa.gov/about-us/smd-programs/living-with-a-star/.

# LIVING WITH A STAR

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Mandatory Budget Authority** | -- | -- | 10.0 | -- | -- | -- | -- |

Living with a Star is supported in part with mandatory funding. The mandatory investment includes $10 million for Living With a Star (LWS) Science, to accelerate efforts in support of the Administration's multi-agency Space Weather Action Plan. Work will include benchmark maturation, implementation of FY2016 plans, and continuation of planning efforts between the agencies. The investment will also augment Living with a Star Research and Analysis elements that address space weather

# SOLAR PROBE PLUS (SPP)

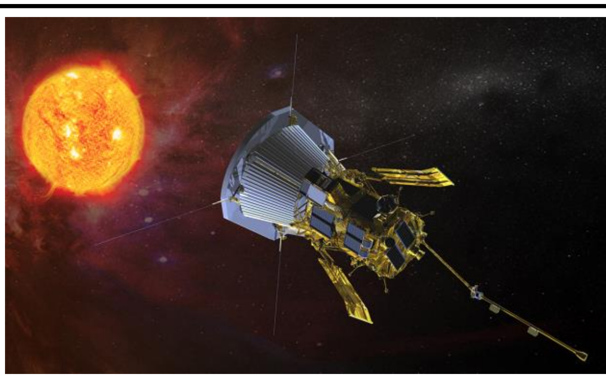
| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Prior | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 | BTC | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Formulation | 247.1 | 0.0 | 0.0 | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 247.1 |
| Development/Implementation | 95.9 | 193.7 | 238.6 | **232.5** | 289.7 | 0.0 | 0.0 | 0.0 | 0.0 | 1050.4 |
| Operations/Close-out | 0.0 | 0.0 | 0.0 | **0.0** | 0.0 | 100.4 | 30.6 | 22.1 | 102.9 | 256.0 |
| **2016 MPAR LCC Estimate** | **343.0** | **193.7** | **238.6** | **232.5** | **289.7** | **100.4** | **30.6** | **22.1** | **102.9** | **1553.5** |
| **Total Budget** | **368.0** | **193.7** | **238.6** | **232.5** | **289.7** | **100.4** | **30.6** | **22.1** | **102.9** | **1578.4** |
| Change from FY 2016 | | | | **-6.1** | | | | | | |
| Percentage change from FY 2016 | | | | **-2.6%** | | | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**Artist's concept of the SPP spacecraft as it approaches the Sun.)**

### PROJECT PURPOSE

SPP will explore the Sun's outer atmosphere, or corona, as it extends out into space. SPP will orbit at a distance from the Sun of less than five times the Sun's diameter, closer than any other spacecraft. SPP will repeatedly obtain direct in-situ coronal magnetic field, plasma, and white-light remote sensing observations in the region that heats the solar atmosphere and accelerates the solar wind. SPP's findings could revolutionize our knowledge and understanding of coronal heating and of the origin and evolution of the solar wind, answering critical questions posed in the 2003 Heliophysics Decadal Survey.

Its seven-year prime mission lifetime will permit observations over a significant portion of a solar cycle. SPP will enable direct sampling of plasma, enabling observations that otherwise are impossible. These observations will allow heliophysicists to verify and discriminate between a broad range of theory and models that describe the Sun's coronal magnetic field and the heating and acceleration of the solar wind. SPP will enable NASA to characterize and forecast the radiation environment in which future space explorers will work and live.

For more information, go to http://nasascience.nasa.gov/missions/solar-probe.

# SOLAR PROBE PLUS (SPP)

| Formulation | Development | Operations |
| --- | --- | --- |

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## PROJECT PARAMETERS

After launch in August 2018, SPP will orbit the Sun 24 times, gradually “walking in” toward the Sun with each pass. SPP’s first close approach to the Sun occurs just three months after launch. Over a period of several years, seven Venus flybys will gradually shrink the spacecraft’s orbit around the Sun. The closest points of each orbit come well within the path of Mercury, the closest planet to the Sun. On the final three orbits, SPP will fly within 3.8 million miles of the Sun’s surface. That is about seven times closer than the Helios spacecraft, the current record holder for the closest solar pass. SPP will sample changes in the solar wind with increasing solar activity.

## ACHIEVEMENTS IN FY 2015

In FY 2015, the project conducted peer level Critical Design Reviews (CDRs) for system and subsystems, leading up to the mission level CDR. After completion of the CDR in March 2015, the project initiated the build of flight hardware and completed the launch vehicle procurement process.

## WORK IN PROGRESS IN FY 2016

In FY 2016, the project will conduct the System Integration Review (SIR), which marks the end of Phase C design and fabrication and the beginning of system assembly, integration, and testing. The SIR assesses the readiness of the subsystems and assemblies, software, and test procedures to begin final assembly. It evaluates the continuing compliance of the system against the applicable requirements and evaluates the readiness to proceed with system assembly and environmental testing.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

In FY 2017, the project will continue system integration and testing. The project will receive and integrate all instruments, and it will deliver the final versions of flight software, flight thermal protection system, and flight solar arrays.

## SCHEDULE COMMITMENTS/KEY MILESTONES

| Milestone | Confirmation Baseline Date | FY 2017 PB Request |
| --- | --- | --- |
| KDP-C | Mar 2014 | Mar 2014 |
| CDR | Mar 2015 | Mar 2015 |
| SIR | Jun 2016 | May 2016 |

# SOLAR PROBE PLUS (SPP)

| Formulation | Development | Operations |
|---|---|---|

| Milestone | Confirmation Baseline Date | FY 2017 PB Request |
|---|---|---|
| Launch | Aug 2018 | Aug 2018 |
| Start of Phase E | Oct 2018 | Oct 2018 |
| End of Prime Mission | Sep 2025 | Sep 2025 |

## Development Cost and Schedule

| Base Year | Base Year Develop-ment Cost Estimate ($M) | JCL (%) | Current Year | Current Year Develop-ment Cost Estimate ($M) | Cost Change (%) | Key Milestone | Base Year Milestone Data | Current Year Milestone Data | Milestone Change (mths) |
|---|---|---|---|---|---|---|---|---|---|
| 2015 | 1,055.7 | 70 | 2016 | 1,050.3 | -0.5 | LRD | Aug 2018 | Aug 2018 | 0 |

*Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.*

## Development Cost Details

NASA confirmed Solar Probe Plus to proceed into implementation phase in March 2014.

| Element | Base Year Development Cost Estimate ($M) | Current Year Development Cost Estimate ($M) | Change from Base Year Estimate ($M) |
|---|---|---|---|
| **TOTAL:** | **1,055.7** | **1,050.3** | **-5.4** |
| Aircraft/Spacecraft | 170.8 | 205.3 | 34.5 |
| Payloads | 143.4 | 145.6 | 2.2 |
| Systems I&T | 31.2 | 31.2 | 0.0 |
| Launch Vehicle | 430.5 | 425.0 | -5.5 |
| Ground Systems | 17.8 | 18.2 | 0.4 |

# SOLAR PROBE PLUS (SPP)

| Formulation | Development | Operations |
|---|---|---|

| Element | Base Year Development Cost Estimate ($M) | Current Year Development Cost Estimate ($M) | Change from Base Year Estimate ($M) |
|---|---|---|---|
| Science/Technology | 4.5 | 6.1 | 1.6 |
| Other Direct Project Costs | 257.5 | 218.9 | -38.6 |

## Project Management & Commitments

GSFC provides program management. JHU-APL manages the project.

| Element | Description | Provider Details | Change from Baseline |
|---|---|---|---|
| Expendable Launch Vehicle | Deliver the spacecraft to operational orbit. | Provider: United Launch Alliance (ULA)<br>Lead Center: KSC<br>Participating Centers: KSC<br>Cost Share Partners: N/A | N/A |
| Ground Systems | Receive science and telemetry data from spacecraft, command spacecraft, and distribute science data to investigator teams. | Provider: JHU-APL<br>Lead Center: GSFC<br>Participating Centers: N/A<br>Cost Share Partners: N/A | N/A |
| Spacecraft | Transport instruments to science destination, operate instruments, and modify orbit, including several Venus gravity assists. | Provider: JHU-APL<br>Lead Center: GSFC<br>Participating Centers: N/A<br>Cost Share Partners: N/A | N/A |
| Instruments | Provide in-situ measurements and remote observations of the Sun. | Provider: NASA funded investigators<br>Lead Center: GSFC<br>Participating Centers: N/A<br>Cost Share Partners: N/A | N/A |

# SOLAR PROBE PLUS (SPP)

| Formulation | Development | Operations |
|---|---|---|

## Project Risks

| Risk Statement | Mitigation |
|---|---|
| If: The spacecraft is unable to resolve time critical faults with sufficient speed,<br>Then: Critical components may be over-exposed to the solar environment, leading to a mission-ending failure. | The project will develop a system response for every manageable fault and perform extensive ground testing and simulation of system fault responses. Management will consider the risk mitigated after these activities are complete. |
| If: The optical properties of the solar array result in a solar array that is colder than expected,<br>Then: The cooling system margin above freezing may fall below acceptable levels, threatening the arrays. | The project will measure the optical properties of the solar array cover glass and perform the power-thermal analysis to assess margin during thermal vacuum testing in FY 2016. Management will consider the risk mitigated after these activities are complete. |

## Acquisition Strategy

Principal Investigators selected through the competitive AO are building the science instruments. JHU-APL builds the spacecraft, and competitively procures the spacecraft subassemblies, components, and parts. The project is refining the ground system components and requirements. GSFC manages the operations contracts.

### MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Prime Contract and Mission Management | JHU-APL | Laurel, MD |
| FIELDS magnetometers and plasma wave instrument | University of California, Berkeley | Berkeley, CA |
| ISIS energetic particle instruments | Southwest Research Institute | San Antonio, TX |
| SWEAP plasma instruments | Smithsonian Astrophysical Observatory | Cambridge, MA |
| WISPR heliospheric imager | Naval Research Laboratory | Washington, DC |
| Heliophysics Origins Investigation | JPL | Pasadena, CA |

# SOLAR PROBE PLUS (SPP)

| Formulation | Development | Operations |
|---|---|---|

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | SRB | Jan 2014 | PDR to assess readiness for KDP-C | Successful, project ready to proceed to development | Mar 2015 |
| Perform-ance | SRB | Mar 2015 | CDR to assess readiness for KDP-D | Successful, project's mission design is appropriately mature to continue with the final design and fabrication phase. | May 2016 |
| Perform-ance | SRB | May 2016 | SIR to assess readiness for project to begin system I&T | TBD | Mar 2018 |
| Perform-ance | SRB | Mar 2018 | ORR to assess readiness for project to operate the flight system | TBD | N/A |
| Perform-ance | SRB | Jan 2014 | PDR to assess readiness for KDP-C | Successful, project ready to proceed to development | Mar 2015 |

# SOLAR ORBITER COLLABORATION (SOC)

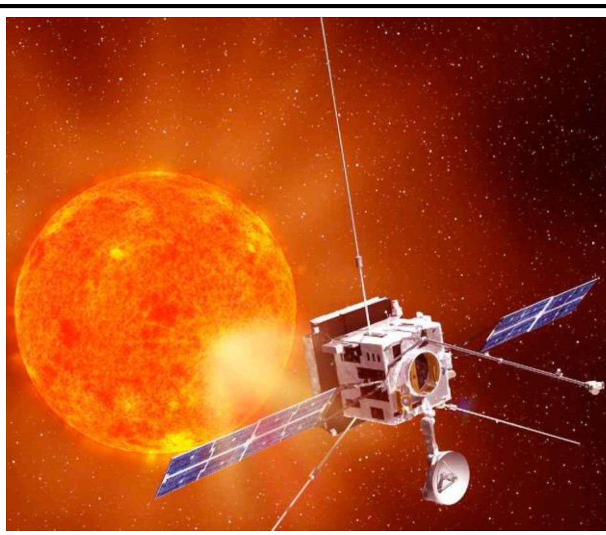
| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Prior | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 | BTC | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Formulation | 41.5 | 0.0 | 0.0 | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 41.5 |
| Development/Implementation | 57.5 | 20.5 | 49.8 | **80.7** | 51.4 | 60.1 | 0.0 | 0.0 | 0.0 | 320.0 |
| Operations/Close-out | 0.0 | 0.0 | 0.0 | **0.0** | 0.0 | 6.2 | 2.3 | 2.4 | 6.6 | 17.5 |
| **2016 MPAR LCC Estimate** | **99.0** | **20.5** | **49.8** | **80.7** | **51.4** | **66.3** | **2.3** | **2.4** | **6.6** | **379.0** |
| **Total Budget** | **99.0** | **20.5** | **49.8** | **80.7** | **51.4** | **66.3** | **2.3** | **2.4** | **6.6** | **379.0** |
| Change from FY 2016 | | | | **30.9** | | | | | | |
| Percentage change from FY 2016 | | | | **62.0%** | | | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**This ESA-led mission will improve the understanding of how the Sun determines the environment of the inner solar system and how fundamental plasma physical processes operate near the Sun.**

## PROJECT PURPOSE

The NASA and ESA SOC mission will provide measurements that will give NASA better insight on the evolution of sunspots, active regions, coronal holes, and other solar features and phenomena. The instruments will explore the near-Sun environment to improve our understanding of the origins of the solar wind streams and the heliospheric magnetic field; the sources, acceleration mechanisms, and transport processes of solar energetic particles; and the evolution of CMEs in the inner heliosphere. To achieve these objectives, SOC will make in-situ measurements of the solar wind plasma, fields, waves, and energetic particles. SOC will also make imaging/spectroscopic observations. SOC will provide close-up views of the Sun’s polar-regions and far side. SOC will tune its orbit to the direction of the Sun’s rotation to allow the spacecraft to observe one specific area for much longer than is currently possible.

ESA provides the spacecraft and operations, the ESA member states provide the majority of the instruments, and NASA provides the launch vehicle and two science investigations/instruments: the Solar

# SOLAR ORBITER COLLABORATION (SOC)

| Formulation | Development | Operations |
|---|---|---|

Orbiter Heliospheric Imager (SoloHI) and the Heavy Ion Sensor (HIS). In return for its contributions, NASA will have access to the entire science mission data set.

For more information, go to http://nasascience.nasa.gov/missions/solar-orbiter.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## PROJECT PARAMETERS

A NASA-provided launch vehicle will place the ESA-provided SOC spacecraft into an inner heliospheric orbit around the Sun, with its closest approach ranging from 0.23 to 0.38 AU and the farthest distance from 0.73 to 0.88 AU. In the first phase of mission operations, SOC will orbit around the Sun's equator at about the same rate as the Sun's rotation. In the second phase, it will perform a Venus gravity assist maneuver between each rotation around the Sun. Each gravity assist maneuver will increase the SOC's inclination with respect to the Sun's equator so that the inclination will reach 27.5 degrees by the end of prime mission operations. This will enable the instruments to image the polar regions of the Sun clearly for the first time and make key measurements that will advance our understanding of the solar dynamo and the polarity reversal of the global magnetic field. The inclination will increase to 34 degrees by the end of a possible three-year extended mission, allowing better insight into the polar-regions.

## ACHIEVEMENTS IN FY 2015

In February, the Naval Research Lab delivered the Electrical Model (ELM) of the SoloHI instrument to Airbus (UK) for integration and testing on their Spacecraft Engineering Testbed (ETB). The HIS and SoloHI teams made significant progress in producing and testing the majority of their instrument sub-assemblies.

## WORK IN PROGRESS IN FY 2016

Flight models of both the SoloHI and HIS instruments will undergo final assembly, environmental testing, and delivery to ESA. NASA and the HIS instrument team will support the integration and testing of the Solar Wind Analyzer suite at the Mullard Space Science Laboratory in the United Kingdom.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA and the instrument teams will support the integration of the HIS and SoloHI instruments into the spacecraft, as well as the observatory-level environmental testing at Airbus facilities in the United Kingdom.

# SOLAR ORBITER COLLABORATION (SOC)

| Formulation | Development | Operations |
|---|---|---|

## SCHEDULE COMMITMENTS/KEY MILESTONES

| Milestone | Confirmation Baseline Date | FY 2017 PB Request |
|---|---|---|
| KDP-C | Mar 2013 | Mar 2013 |
| SoloHI Instrument CDR | Jun 2013 | Oct 2013 |
| HIS Instrument CDR | Feb 2014 | Mar 2014 |
| Pre-ship review | Jan 2015 | Jul 2016 |
| Launch | Oct 2018 | Oct 2018 |
| Begin Phase E | Oct 2018 | Jan 2019 |
| End of Prime Mission | Nov 2026 | Dec 2025 |

## Development Cost and Schedule

| Base Year | Base Year Develop-ment Cost Estimate ($M) | JCL (%) | Current Year | Current Year Develop-ment Cost Estimate ($M) | Cost Change (%) | Key Milestone | Base Year Milestone Data | Current Year Milestone Data | Milestone Change (mths) |
|---|---|---|---|---|---|---|---|---|---|
| 2014 | 376.9 | N/A | 2016 | 320.0 | -15.1 | LRD | Oct 2018 | Oct 2018 | 0 |

*Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.*

## Development Cost Details

NASA confirmed SOC to proceed into implementation phase in March 2013. The current year development cost reflects the award of the launch vehicle contract.

| Element | Base Year Development Cost Estimate ($M) | Current Year Development Cost Estimate ($M) | Change from Base Year Estimate ($M) |
|---|---|---|---|
| **TOTAL:** | **376.9** | **320.0** | **-56.9** |

# SOLAR ORBITER COLLABORATION (SOC)

| Formulation | Development | Operations |
| --- | --- | --- |

| Element | Base Year Development Cost Estimate ($M) | Current Year Development Cost Estimate ($M) | Change from Base Year Estimate ($M) |
| --- | --- | --- | --- |
| Aircraft/Spacecraft | 0.0 | 0.0 | 0.0 |
| Payloads | 23.7 | 45.8 | 22.1 |
| Systems I&T | 0.0 | 0.0 | 0.0 |
| Launch Vehicle | 250.0 | 172.7 | -77.3 |
| Ground Systems | N/A | N/A | N/A |
| Science/Technology | 1.3 | 1.4 | 0.1 |
| Other Direct Project Costs | 101.9 | 100.1 | -1.8 |

## Project Management & Commitments

GSFC has program management responsibility for the LWS program and the SOC project. NASA procured all instruments provided by the United States through a competitive AO.

| Element | Description | Provider Details | Change from Baseline |
| --- | --- | --- | --- |
| SoloHi | Measures the solar wind formations, shock disturbance, and turbulence. | Provider: Naval Research Lab<br>Lead Center: GSFC<br>Performing Center(s): GSFC<br>Cost Share Partner(s): N/A | N/A |
| HIS | Measures the range of heavy ion energies, charge states, masses, and elevation angles as part of the United Kingdom-provided Solar Wind Analyzer instrument suite. | Provider: Southwest Research Institute<br>Lead Center: GSFC<br>Performing Center(s): N/A<br>Cost Share Partner(s): N/A | N/A |
| Expendable Launch Vehicle | Launch vehicle | Provider: ULA<br>Lead Center: KSC<br>Performing Center(s): KSC<br>Cost Share Partner(s): N/A | N/A |

# SOLAR ORBITER COLLABORATION (SOC)

| Formulation | Development | Operations |
|---|---|---|

## Project Risks

| Risk Statement | Mitigation |
|---|---|
| If: ESA hardware delivery for launch is delayed,<br>Then: NASA launch vehicle and development costs will increase. | Monitor ESA's progress during its hardware development and plan to cover ESA schedule overruns. |

## Acquisition Strategy

NASA selected the instruments and science investigations from a competed AO. NASA competitively selected the launch vehicle through the NASA Launch Services-II contract.

### MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
|---|---|---|
| SoloHI | Naval Research Lab | Washington, DC |
| Heavy Ion Sensor | Southwest Research Institute | San Antonio, TX |

### INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | SRB | Mar 2013 | PDR to assess readiness for KDP-C | Successful, project ready to proceed to development | Jul 2015 |
| Perform-ance | SRB | Oct 2013 | SoloHI Instrument to assess readiness for CDR | Successful | Jul 2016 |
| Perform-ance | SRB | Mar 2014 | HIS Instrument to assess readiness for CDR | Successful | Jul 2016 |
| Perform-ance | SRB | Jul 2016 | Pre-ship Review to assess readiness for shipment to ESA | | |

# SOLAR ORBITER COLLABORATION (SOC)

| Formulation | Development | Operations |
|---|---|---|

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | SRB | Oct 2018 | Operations Readiness Review/Mission Readiness Review to assess readiness for KDP-E | | |

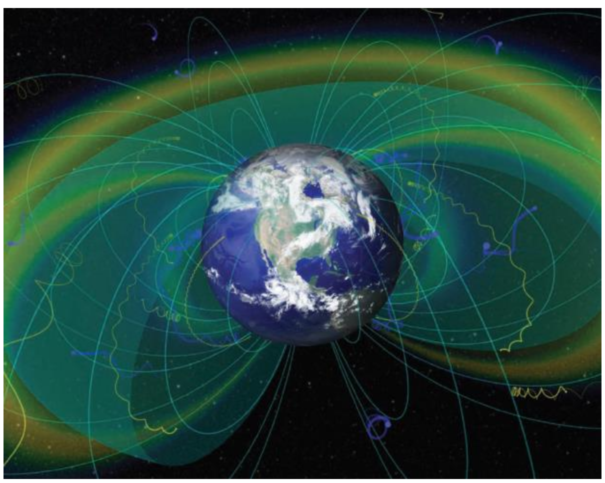
# OTHER MISSIONS AND DATA ANALYSIS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| LWS Space Environment Testbeds | 0.4 | -- | **0.4** | 0.0 | 0.0 | 0.0 | 0.0 |
| LWS Science | 17.4 | -- | **27.5** | 24.0 | 30.5 | 30.3 | 30.3 |
| LWS Program Management and Future Missions | 5.3 | -- | **7.8** | 8.9 | 22.3 | 51.7 | 60.5 |
| Van Allen Probes (RBSP) | 13.0 | -- | **13.3** | 13.0 | 13.0 | 9.0 | 0.0 |
| Solar Dynamics Observatory (SDO) | 13.1 | -- | **12.0** | 11.8 | 12.0 | 12.0 | 12.0 |
| Balloon Array for Radiation-belt Relativistic Electron Losses (BARREL) | 0.2 | -- | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| **Total Budget** | **49.4** | **--** | **61.0** | **57.7** | **77.9** | **103.0** | **102.8** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**The Van Allen Belts (depicted as bands with an orange/yellow/green hue in the image above) were the first significant discovery of the space age. Scientists have learned that the two belts of energetic ions and electrons can wax, wane, merge, or even (as NASA's Van Allen Probes discovered) separate and divide into three belts. In 2014, researchers used Van Allen Probes data to discover a sharp edge in the outer belt that forms a barrier that the fastest, highest-energy electrons simply cannot penetrate.**

The LWS Other Missions and Data Analysis budget includes operating LWS missions, a science research program, program management, and funding for missions to launch in the next decade.

For more information, go to http://science.nasa.gov/about-us/smd-programs/living-with-a-star/.

## Mission Planning and Other Projects

### LWS SPACE ENVIRONMENT TESTBEDS

The SET project seeks to improve the accommodation and/or mitigation of the effects of solar variability on spacecraft. It addresses the identification and understanding of the mechanisms of space environment interactions, modeling of these interactions, and development and validation of ground test protocols to qualify technologies for space. As the complexity of the technologies increases, models derived from the physics-based understanding of the effects are required, and the SET mission responds to these needs. The SET mission will get to medium-Earth orbit as a rideshare payload on the Air Force Research Laboratory's Demonstration and Space Experiments (DSX) spacecraft, with the launch expected in late-2016.

### Recent Achievements

Delivery of all SET flight hardware is complete, including the separation system for the DSX secondary payload. NASA completed vibration and thermal vacuum testing in December 2015. Activities scheduled for FY 2016 include work with the separation system, interface testing, mission readiness review (MRR), and four rehearsals.

All SET experiment teams are continuing research on code development, designed to supplement SET experiments. In collaboration with JSC and MSFC, the project developed an updated database of solar particle events (CMEs and solar flares), and will distribute the database via the SET website.

## LWS SCIENCE

Understanding space weather and improving the capability to address problems, such as predicting geomagnetic storms, pose two major challenges for the research community. First, research must couple traditionally separate disciplines in heliophysics, such as solar-heliospheric and geospace physics. Second, to be truly successful, research must also demonstrate how results would enable an operational capability, such as the generation of forecasts for geomagnetic storms.

LWS Science addresses these challenges through three main approaches:

- Builds infrastructure: The infrastructure component includes funding to train the next generation of heliophysics experts, conduct a heliophysics graduate-level summer school, develop graduate course content, and support a limited number of space weather postdoctoral positions at universities and government laboratories.
- Addresses scientific needs: The goal of the project is to develop the scientific understanding needed for the United States to address those aspects of Heliophysics science that may affect life and society. To ensure this, the Targeted Research & Testing (TR&T) element solicits large-scale problems that cross discipline and technique boundaries. This leads to a physics-based understanding of the integral system linking the Sun to the solar system both directly and via the heliosphere, planetary magnetospheres, and ionospheres. The proposals identify how this new understanding will have a direct impact on life and society. In addition, TR&T supports the Sun-Climate objective whose goal is to deliver the understanding of how and to what degree variations in the solar radiative and particulate output contribute to changes in global and regional climate over a wide range of time scales. TR&T also supports the development of tools and methods needed to achieve the LWS goals.
- Addresses strategic capabilities: A primary goal of this project is the development of first-principles-based models for the coupled Sun-Earth and Sun-solar system, similar in spirit to the first-principles models for the lower terrestrial atmosphere. Such models can act as tools for science investigations, as prototypes and test beds for prediction and specification capabilities, as frameworks for linking disparate data sets at vantage points throughout the Sun-solar system, and as strategic planning aids for enabling exploration of space and testing new mission concepts. Strategic capabilities are the development and integration of such models for all the various components of this system. These models have reached a level of maturity that enables integration into scientific and operational deliverables (e.g., models or tools) that are broadly

useful to the larger community in universities, government laboratories, industry, and the military.

### Recent Achievements

New observations of solar energetic particles (SEPs) yielded a number of surprises. The recent solar cycle produced sixteen ground-level events in ground-based neutron monitors, which allowed us to establish that most large SEP events are preceded by a CME from the same solar active region. This indicates that the most intense events may involve the acceleration of particles in one or more flares that produce a seed population of energetic ions that can then reach very high energy by the CME driven shock. Continuing observations from STEREO, ACE and other platforms as well as upcoming SOC and SPP missions will provide key measurements in the source regions of these events and their spatial extent and evolution so that the complex dynamics of SEP acceleration and transport to the geospace environment can be unraveled. Understanding large SEP events is central to space weather and space climate.

Using data from the Hinode satellite, a NASA and JAXA joint mission, and the SDO, scientists discovered that small-scale filament eruptions are the driver of solar coronal hole X-ray jets. Solar X-ray jets are explosions that erupt from the Sun's surface, expelling hot gas into the corona, the Sun's outer atmosphere. The generally accepted theory, the Emerging-Flux Model, which states that new flux ascending to the photosphere and its interaction with the photosphere's complex magnetic topology creates the jets, did not accurately explain what was occurring. Rather, filament eruptions caused these jets—very small, scaled down filament eruptions. A filament is a structure in the corona that consists of cool plasma, supported by magnetic fields. Earlier satellites recording the eruptions could not separate the two occurrences, essentially hiding the filament. Advances in technology with the Hinode and SDO made it possible to separate the filament from the eruption by observing the event at different wavelengths.

The solar activity cycle peaks approximately every 11 years. New research shows evidence of a shorter time cycle as well, with activity waxing and waning over the course of about 330 days. Understanding when to expect such bursts of solar activity is crucial to successfully forecasting the Sun's eruptions, which can drive solar storms at Earth. These space weather events can interfere with satellite electronics, GPS navigation, and radio communications. Recent results indicate that changes in bands of strong magnetic field located in each solar hemisphere drive the 330-day variations in solar storms. This new study examines what creates the magnetic bands and how they influence solar cycles. Researchers detected the bands by drawing on a host of NASA satellites and ground-based observatories that observe the Sun and its output. They noted the changes in the magnetic field in the bands gives rise to a 330-day activity cycle on the Sun that is directly observable, but has not been previously investigated when trying to understand the longer 11-year cycle. Researchers are now turning to advanced computer simulations and focused observations to learn more about the influence of these bands on solar activity. By obtaining a better understanding of the patterns of solar activity in each hemisphere, scientists gain deeper knowledge about the solar cycle, and when combined with modeling efforts, improve space weather forecasting efforts.

## LWS PROGRAM MANAGEMENT AND FUTURE MISSIONS

Program Management and Future Missions provide the resources required to manage the planning, formulation, and implementation of all LWS missions. The office resolves technical and programmatic issues and risks, monitors and reports on progress, and is responsible for achieving overall LWS cost and schedule goals. In addition, Future Missions support strategic planning for addressing the LWS recommendations of the Heliophysics decadal survey, and the pre-formulation activities for missions that are still merely concepts.

# Operating Missions

## VAN ALLEN PROBES (FORMERLY RADIATION BELT STORM PROBES)

The Van Allen Probes mission is helping scientists to understand the Sun's influence on Earth and near-Earth space by studying Earth's radiation belts on various scales of space and time. The mission observes the processes that energize and transport radiation belt electrons and ions in Earth's inner magnetosphere, the area in and around Earth's radiation belts. These observations are providing new knowledge on the dynamics and extremes of the radiation belts that are important to all technological systems that fly in and through geospace. The mission will enable an understanding, ideally to the point of predictability, of how populations of relativistic electrons and penetrating ions in space form or change in response to variable inputs of energy from the Sun.

### Recent Achievements

The Van Allen Belts, named for their discoverer James Van Allen, are two donut-shaped regions encircling Earth, where our planet's magnetic field traps charged particles from the Sun and space. Researchers used data from the Van Allen Probes to discover a sharp inner edge in the outer belt that acts as a barrier, preventing high-energy electrons from coming closer to Earth. This work enables us to better quantify potential dangers to astronauts and technological assets in low Earth orbit.

## SOLAR DYNAMICS OBSERVATORY (SDO)

Launched on February 11, 2010, the SDO seeks to understand the Sun's influence on Earth and near-Earth space by simultaneously studying the solar atmosphere on small scales of space and time and in many wavelengths. The observatory enables scientists to determine how the Sun's magnetic field is generated and structured and how stored magnetic energy is converted and released in the form of solar wind, energetic particles, and variations in the solar irradiance. SDO collects data to help explain the creation of solar activity, which drives space weather. Measurements of the interior of the Sun, the Sun's magnetic field, the hot plasma of the solar corona, and the irradiance that creates Earth's ionosphere are the primary data products. Currently in its prime operations phase, SDO's images and spectra are key sources of data at solar science conferences and further advance knowledge of the Sun.

### Recent Achievements

Researchers recently found that the amount of extreme ultraviolet light from the Sun's atmosphere or corona can decrease when the Sun emits a CME. CMEs can contain up to one billion tons of material, travel at up to one million miles per hour, and play a major role in space weather events that affect Earth and planets throughout the solar system. Using data from SDO's Extreme Ultraviolet Variability Experiment (EVE), the dimming of the extreme ultraviolet spectra correlates with both the speed and amount of material within the CME. These new insights will improve predictions of solar explosive events. Other new results show that coronal heating is more complex than originally thought, with the dominant mechanisms likely dependent on local conditions. Scientists used data from IRIS and SDO to reveal evidence for an alternative heating mechanism in which small events called nanoflares release magnetic energy. Comparisons between numerical models and high -resolution observations of these nanoflares show how particles accelerate to very high energies and speeds that heat small pockets of gas to temperatures of millions of degrees and propelling the gas upward into the corona.

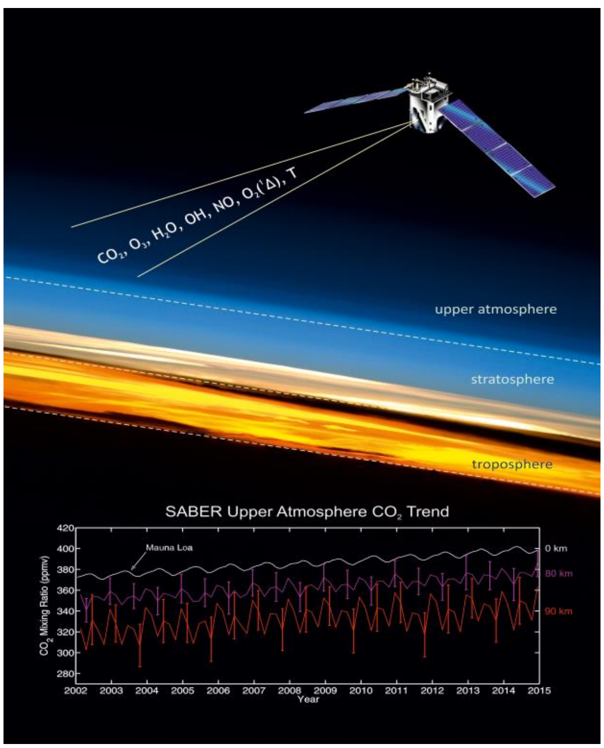
# SOLAR TERRESTRIAL PROBES

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Other Missions and Data Analysis | 70.6 | -- | **39.8** | 38.8 | 127.3 | 179.4 | 198.4 |
| **Total Budget** | **70.6** | **--** | **39.8** | **38.8** | **127.3** | **179.4** | **198.4** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*




**NASA's TIMED mission has confirmed a surprisingly fast carbon dioxide increase in Earth's upper atmosphere using 14 years of data from a radiometer aboard the satellite. Furthermore, TIMED data revealed that the carbon dioxide in these upper layers, long thought to follow the same patterns across the globe, is increasing faster over the Northern Hemisphere. Understanding the way carbon dioxide moves throughout the atmosphere is key, both for making accurate climate models and for planning spacecraft orbits..**

STP focuses on understanding the fundamental physical processes of the space environment, from the Sun to the Earth, other planets, and beyond to the interstellar medium. STP provides insight into the basic processes of plasmas (fluid of charged particles) inherent in all astrophysical systems. STP missions focus on processes such as the variability of the Sun, responses of the planets to those variations, and the interaction of the Sun and the solar system. NASA defines specific goals for STP missions and selects investigations for each mission competitively. These missions allow the science community an opportunity to address important research focus areas and make significant progress in understanding fundamental physics.

For more information, go to http://science.nasa.gov/about-us/smd-programs/solar-terrestrial-probes/.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## ACHIEVEMENTS IN FY 2015

MMS launched on an Atlas V launch vehicle from Cape Canaveral Air Force Station on March 12, 2015. Mission science operations commenced September 1 following a period of commissioning and orbital adjustments.

# SOLAR TERRESTRIAL PROBES

### WORK IN PROGRESS IN FY 2016

Operations of MMS, STEREO, Hinode, and TIMED continue.

### KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA plans to release an AO for the STP-5 mission and a Mission of Opportunity (MO).

## Program Schedule

| Date | Significant Event |
|---|---|
| FY 2017 | AO for an STP-5 Mission and MO |
| FY 2018 | STP-5 and MO KDP-A |

## Program Management

The STP program manager resides at GSFC.

## Acquisition Strategy

In the acquisition of STP scientific instruments, spacecraft, and science investigations (including Research and Analysis), NASA will use full and open competitions to the greatest extent possible. NASA may acquire certain instruments, missions, or mission systems without competition (e.g., through international partnerships or in-house builds), if there is a clear scientific, technological, or programmatic benefit to NASA to do so. NASA will acquire launch vehicles through existing contracts, managed by the HEOMD, except when an international partner provides them under an approved agreement.

### INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Program Independ-ent Review | SRB | Nov 2014 | Assess performance of program | Successful | Oct 2019 |

# OTHER MISSIONS AND DATA ANALYSIS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| STP Program Management and Future Missions | 0.4 | -- | **3.4** | 5.7 | 97.4 | 149.4 | 175.4 |
| Magnetospheric Multiscale (MMS) | 52.4 | -- | **17.4** | 14.6 | 11.0 | 11.0 | 4.0 |
| Solar Terrestrial Relations Observatory (STEREO) | 7.5 | -- | **9.5** | 9.3 | 9.5 | 9.5 | 9.5 |
| Hinode (Solar B) | 7.5 | -- | **7.0** | 6.8 | 7.0 | 7.0 | 7.0 |
| TIMED | 2.8 | -- | **2.6** | 2.4 | 2.5 | 2.5 | 2.5 |
| **Total Budget** | **70.6** | -- | **39.8** | **38.8** | **127.3** | **179.4** | **198.4** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**Following a successful launch on March 12, 2015, NASA's Magnetospheric Multiscale (MMS) spacecraft began the first space mission dedicated to the study of a phenomenon called magnetic reconnection. This process occurs when magnetic fields connect, disconnect, and reconfigure explosively. These explosions can send particles surging through space near the speed of light. MMS is currently providing the first three-dimensional views of reconnection occurring in Earth's protective magnetic space environment known as the magnetosphere.**

The STP Other Missions and Data Analysis budget includes operating STP missions, program management, and funding for future missions launching in the next decade.

For more information, go to http://stp.gsfc.nasa.gov.

# Mission Planning and Other Projects

## PROGRAM MANAGEMENT AND FUTURE MISSIONS

Program Management and Future Missions provide the resources required to manage the planning, formulation, and implementation of all STP missions. The program office ensures successful achievement of STP program cost and schedule goals, while managing cross-project dependencies, risks, issues, and requirements as projects progress through formal key decision points. In addition, Future Missions supports the STP program strategic planning for addressing the recommendations of the Heliophysics decadal survey and the pre-formulation activities for STP missions not yet approved as projects.

# OTHER MISSIONS AND DATA ANALYSIS

## Operating Missions

### MAGNETOSPHERIC MULTISCALE (MMS)

The MMS mission investigates how the magnetic fields of the Sun and Earth connect and disconnect, explosively transferring energy from one to the other. This magnetic reconnection process occurs throughout the universe. MMS uses Earth's magnetosphere as a natural laboratory to study the microphysics of magnetic reconnection, a fundamental plasma-physical process that converts magnetic energy into heat and charged particle kinetic energy. In addition to seeking to solve the mystery of the small-scale physics of the reconnection process, MMS will investigate how the energy conversion that occurs in magnetic reconnection accelerates particles to high energies and what role plasma turbulence plays in reconnection events. Magnetic reconnection, particle acceleration, and turbulence occur in all astrophysical plasma systems, but researchers can only study them in-situ in the solar system, and most efficiently in Earth's magnetosphere, where these processes control the dynamics of the geospace environment and play an important role in the phenomena known as space weather.

The MMS mission consists of four identically instrumented spacecraft that measure particles, fields, and plasmas. The MMS instrument payload measures electric and magnetic fields and the plasmas found in the regions where magnetic reconnection occurs. Fast, multi-point measurements are enabling dramatically revealing direct observations of these physical processes. A highly elliptical orbit explores how Sun-Earth magnetic fields reconnect in Earth's neighborhood. The four spacecraft fly in a tetrahedron formation that allows them to observe the three dimensional structure of magnetic reconnection events. The separation between the observatories is adjustable over a range of 6 to 250 miles during science operations in the area of interest.

For more information, go to http://science.nasa.gov/missions/mms/.

#### Recent Achievements

MMS launched on an Atlas V launch vehicle from Cape Canaveral Air Force Station on March 12, 2015. Mission science operations commenced September 1, following a period of commissioning and orbital adjustments. All four observatories that comprise MMS are collecting science data. On Oct. 15, 2015, a NASA mission broke its own record: the four satellites of its MMS mission are now flying at their smallest separation, the tightest multi-spacecraft formation ever flown in orbit. The four spacecraft are just six miles apart, flying in a tetrahedral formation, with each spacecraft at the tip of a four-sided pyramid. The close formation is all the more impressive as the spacecraft speed along at up to 15,000 miles per hour and, with their booms extended, each spacecraft covers as much area as a professional baseball stadium.

### SOLAR TERRESTRIAL RELATIONS OBSERVATORY (STEREO)

STEREO enables studies of the origin of the Sun's CMEs and their consequences for Earth, other planets, and interplanetary space. The mission consists of two spacecraft, one (STEREO-A) ahead and the other (STEREO-B) behind Earth in its orbit. STEREO's instrumentation targets the fundamental process of energetic particle acceleration in the low solar corona and in interplanetary space. The mission can image the structure and evolution of solar storms as they leave the Sun and move through space toward Earth. The mission also provides the foundation for understanding space weather events and developing predictive models. The models in turn, help to identify and mitigate the risks associated with space weather events. In addition, STEREO improves our space weather situational awareness not only for Earth and in low Earth orbit, but also throughout the solar system.

On October 1, 2014, NASA lost communication with STEREO-B, just as the spacecraft was about to orbit around the other side of the sun. In late 2015 the spacecraft finally emerged from behind the sun, so that it can again receive radio signals. NASA will attempt to re-establish contact in March 2016.

### Recent Achievements

New observations provide key clues regarding the acceleration processes in the corona and the efficient transport of SEPs in space. The enormous improvement in solar imaging resulting from the SDO, observations at different locations around the Sun from the STEREO spacecraft, and the very sensitive measurements of energetic Helium-3 ions from sensors on ACE have recently allowed researchers to identify several significant new properties of these small SEP events. For the first time, these direct observations have connected several Helium-3 rich SEP events with sources beyond the solar limb, further confirming the unexpected large spread of these particles in the interplanetary medium.

## HINODE

Hinode is a joint JAXA and NASA mission, operating as a follow-on to the highly successful Japan, United States, and United Kingdom Yohkoh (Solar-A) collaboration. The mission consists of a coordinated set of optical, extreme ultraviolet, and X-ray instruments that are studying the basic heating mechanisms and dynamics of the active solar corona. By investigating the fundamental processes that connect the Sun’s magnetic field and the solar corona, Hinode is discovering how the Sun generates magnetic disturbances and the high-energy particle storms that propagate from the Sun to Earth.

### Recent Achievements

Using magnetic data from the surface of the Sun obtained by Hinode, observations show something called a magnetic flux rope builds up over time until it is so unstable that even the slightest perturbation will produce a CME. Understanding what triggers CMEs is crucial for better understanding of our Sun, and for predicting when such giant explosions might happen. By measuring and calculating the magnetic fields on the Sun, coupled with determining how to measure the critical tipping point where a CME can erupt, this study offers new ways to determine the possibility of eruption from any given active area on the Sun.

## THERMOSPHERE, IONOSPHERE, MESOSPHERE ENERGETICS AND DYNAMICS (TIMED)

The TIMED mission characterizes and studies the physics, dynamics, energetics, thermal structure, and composition of the least explored and understood region of Earth’s atmosphere, the mesosphere-lower thermosphere-ionosphere (MLTI). This region of interest, located between altitudes of approximately 35 to 100 miles above the surface of Earth, helps protect Earth from harmful solar radiation. It is a gateway between Earth’s environment and space, where the Sun’s energy first affects Earth’s environment.

# OTHER MISSIONS AND DATA ANALYSIS

## Recent Achievements

Gravity waves, waves in the atmosphere similar to ocean tides, play an important part in the dynamics of Earth's atmosphere, transferring energy and momentum over large distances, and driving winds in the upper mesosphere. For the first time, a new whole-atmosphere circulation model resolves gravity waves down to the tens of kilometers level. The model reproduces temperature features seen by the Sounding of the Atmosphere using Broadband Emission Radiometry instrument on the NASA Heliophysics TIMED satellite, and reveals the growth and spatial extent of these waves as they propagate to high altitudes. The new simulation revealed a tropical cyclone directly caused the planetary-scale extent of a group of waves about 60 miles above the Earth's surface. The model shows the increasing dominance of gravity waves at higher altitudes, and is uncovering important details of their effects on the atmosphere.

Additionally, TIMED observations show that the carbon dioxide concentration in Earth's upper atmosphere increases at more than twice the average rate observed at the surface, and the rate of increase is greater in the Northern Hemisphere than in the Southern Hemisphere. The increased carbon dioxide actually causes a long-term cooling in the Earth's upper atmosphere and a corresponding atmospheric contraction. This leads to consequences in our space environment, where radio communications occur and spacecraft fly. Therefore, in order to predict and mitigate changes in the space environment, it is critical that we keep monitoring the carbon dioxide level not only in the troposphere, but also in the upper atmosphere.

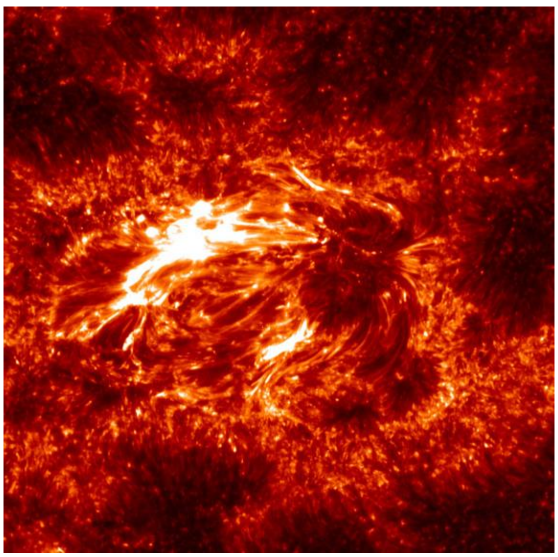
# HELIOPHYSICS EXPLORER PROGRAM

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Ionospheric Connection Explorer (ICON) | 61.0 | 48.4 | **49.4** | 9.0 | 4.5 | 1.3 | 0.0 |
| Other Missions and Data Analysis | 48.9 | -- | **55.2** | 45.6 | 111.8 | 182.5 | 184.0 |
| **Total Budget** | **110.0** | -- | **104.6** | **54.5** | **116.3** | **183.8** | **184.0** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**The Sun's outer atmosphere or corona is mysteriously heated to millions of degrees. One leading theory for the heating of the hot corona invokes the presence of nanoflares, small events of magnetic reconnection that release enough energy to locally heat the plasma to millions of degrees. IRIS observations showed high energy particles generated by individual nanoflare events impacting the chromosphere for the first time. This data provides new insight into how these electrons are accelerated to such high energies. Credit: IRIS: LMSAL, NASA.**

The Heliophysics Explorer Program provides frequent flight opportunities for world-class scientific investigations on focused and timely science topics. Explorers use a suite of smaller, fully competed missions that address these topics to complement the science of strategic missions of the LWS and STP programs. Competitive selections ensure accomplishment of the most current and best science.

The Explorers Program provides several classes (Medium Explorers-MIDEX and Small Explorers-SMEX) of flight opportunities to accomplish the goals of the science program. These mission classes enable NASA to increase the number of flight opportunities in response to recommendations from the scientific community.

The 2011 NASA AO introduced a new class of flight opportunity, the Explorers (EX) missions, in response to the currently available expendable launch vehicles. EX missions fall between the SMEX and MIDEX class missions. Awarded missions will utilize one of the several, lower-cost expendable launch vehicles available through NASA’s Launch Services Program.

Explorer Missions of Opportunity (MO) are smaller investigations, typically an instrument, characterized as being part of a host space mission, sub-orbital flight, small complete missions, and new science investigations using existing spacecraft or ISS-attached payloads.

Other Missions and Data Analysis supports numerous operating Heliophysics Explorer missions, as well as program management functions and funding for future mission selections.

# HELIOPHYSICS EXPLORER PROGRAM

For more information on Explorer missions, go to http://science.nasa.gov/about-us/smd-programs/explorers/.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## ACHIEVEMENTS IN FY 2015

The Explorer Program Office successfully completed the Heliophysics Program Implementation Review in November 2014. This review is an independent assessment that validates the strategic direction and implementation of the Explorer, STP, and LWS flight programs.

## WORK IN PROGRESS IN FY 2016

NASA plans to release an AO in the early spring of 2016 that will solicit proposals for SMEX missions to accomplish Heliophysics Explorer Program science objectives. NASA also plans to release simultaneously a solicitation for Heliophysics Explorer MO through a NASA Announcement of Opportunity, Second Stand Alone Missions of Opportunity Notice (SALMON-2). A draft SMEX AO and draft SALMON-2 Program Element Appendix (PEA) should be ready for release for comment by March 2016.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA will make new mission selections for competitive Phase A study.

# Program Schedule

| Date | Significant Event |
|---:|---|
| Spring/early Summer 2016 | AO announcement of SMEX and MO opportunity to propose |
| Spring 2017 | SMEX and Explorer MO KDP-A |
| Late Summer/fall 2018 | Down select one SMEX and one MO mission for implementation |
| FY 2019 | AO announcement for MIDEX and MO opportunity to propose |
| FY 2020 | MIDEX and Explorer MO KDP-A |
| FY 2021 | Down select one MIDEX and one MO mission for implementation |

# HELIOPHYSICS EXPLORER PROGRAM

## Program Management

The Heliophysics and Astrophysics Explorer elements are both coordinated sets of uncoupled missions, wherein each mission is independent and has unique science, and share a common program office at GSFC and a common management structure. The Explorer program manager resides at GSFC, reporting functionally to the Center Director and programmatically through the Heliophysics and Astrophysics Division Directors to the Associate Administrator for SMD.

## Acquisition Strategy

NASA competitively selects new Explorer missions, releasing solicitations when available funding allows, with the expectation of a three-year cadence. NASA acquires launch vehicles through existing contracts held by the HEOMD, except when an international partner provides them under an approved agreement or when the Explorer mission is not a primary payload on the launch vehicle.

### INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Program Independ-ent Review | SRB | Nov 2014 | Assess performance of program | Successful | Oct 2019 |

# IONOSPHERIC CONNECTION EXPLORER (ICON)

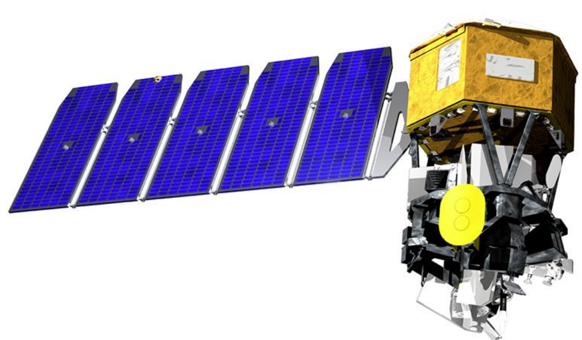
| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| | | Actual | Enacted | Request | Notional | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Budget Authority (in $ millions)** | **Prior** | **FY 2015** | **FY 2016** | **FY 2017** | **FY 2018** | **FY 2019** | **FY 2020** | **FY 2021** | **BTC** | **Total** |
| Formulation | 42.4 | 0.0 | 0.0 | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 42.4 |
| Development/Implementation | 36.6 | 61.0 | 48.4 | **46.8** | 2.9 | 0.0 | 0.0 | 0.0 | 0.0 | 195.7 |
| Operations/Close-out | 0.0 | 0.0 | 0.0 | **2.6** | 6.1 | 4.5 | 1.3 | 0.0 | 0.0 | 14.5 |
| **2016 MPAR LCC Estimate** | **79.0** | **61.0** | **48.4** | **49.4** | **9.0** | **4.5** | **1.3** | **0.0** | **0.0** | **252.6** |
| **Total Budget** | **79.0** | **61.0** | **48.4** | **49.4** | **9.0** | **4.5** | **1.3** | **0.0** | **0.0** | **252.7** |
| Change from FY 2016 | | | | **1.0** | | | | | | |
| Percentage change from FY 2016 | | | | **2.1%** | | | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**ICON will explore the boundary between Earth and space to understand the physical connection between our world and our space environment.**

### PROJECT PURPOSE

Ionospheric Connection Explorer (ICON) is a single spacecraft mission dedicated to understanding neutral-ion coupling in the Earth's upper atmosphere, also known as the thermosphere. It will resolve both long-standing and newly emerging questions about the mechanisms that control the daily development of plasma in Earth's space environment.

### EXPLANATION OF MAJOR CHANGES IN FY 2017

The budget reflects the approved KDP-C cost and schedule baselines.

### PROJECT PARAMETERS

ICON will simultaneously measure altitude profiles of the thermosphere and ionosphere's neutral winds, composition, density, temperature, and ion density. At the same time, it will make in-situ plasma measurements. Three institutions with a successful record of accomplishment of previous space missions will build the four high-heritage scientific instruments of ICON. The payload will fly on an Orbital ATK,

# IONOSPHERIC CONNECTION EXPLORER (ICON)

| Formulation | Development | Operations |
|---|---|---|

LEOStar-2 spacecraft bus with heritage from Solar Radiation and Climate Experiment (SORCE), Aeronomy of Ice in the Mesosphere (AIM), Orbiting Carbon Observatory (OCO), Glory, and Nuclear Spectroscopic Telescope Array (NuSTAR). ICON will provide the data to "understand how neutral winds control ionospheric variability," which is a goal in the 2010 Science Plan for NASA's SMD.

## ACHIEVEMENTS IN FY 2015

NASA confirmed ICON to proceed into implementation phase (Phase C/D) on October 29, 2014. The project completed CDR on April 10, 2015.

## WORK IN PROGRESS IN FY 2016

The Project is continuing development, will complete the system integration review and will proceed to observatory integration and test by the end of FY 2016.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

The Project will complete observatory integration and Pre-Ship Review.

## SCHEDULE COMMITMENTS/KEY MILESTONES

| Milestone | Confirmation Baseline Date | FY 2017 PB Request |
|---|---|---|
| KDP-C | Oct 2014 | Oct 2014 |
| CDR | Apr 2015 | Apr 2015 |
| SIR | Jun 2016 | Jun 2016 |
| Launch | Oct 2017 | Oct 2017 |
| Start of Phase E | Nov 2017 | Nov 2017 |
| End of Prime Mission | Dec 2019 | Dec 2019 |

# IONOSPHERIC CONNECTION EXPLORER (ICON)

| Formulation | Development | Operations |
|---|---|---|

## Development Cost and Schedule

| Base Year | Base Year Develop-ment Cost Estimate ($M) | JCL (%) | Current Year | Current Year Develop-ment Cost Estimate ($M) | Cost Change (%) | Key Milestone | Base Year Milestone Data | Current Year Milestone Data | Milestone Change (mths) |
|---|---|---|---|---|---|---|---|---|---|
| 2015 | 196.0 | 70 | 2016 | 195.8 | (0.2) | LRD | Oct 2017 | Oct 2017 | 0 |

*Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.*

## Development Cost Details

NASA confirmed ICON to proceed into implementation in October 2014.

| Element | Base Year Development Cost Estimate ($M) | Current Year Development Cost Estimate ($M) | Change from Base Year Estimate ($M) |
|---|---|---|---|
| **TOTAL:** | **196.0** | **195.8** | **-0.2** |
| Aircraft/Spacecraft | 29.8 | 35.5 | 5.7 |
| Payloads | 35.8 | 40.0 | 4.2 |
| Systems I&T | 9.4 | 9.4 | 0.0 |
| Launch Vehicle | 54.3 | 56.3 | 2.0 |
| Ground Systems | 2.9 | 3.1 | 0.2 |
| Science/Technology | 3.0 | 2.8 | -0.2 |
| Other Direct Project Costs | 60.8 | 48.7 | -12.1 |

# IONOSPHERIC CONNECTION EXPLORER (ICON)

| Formulation | Development | Operations |
|---|---|---|

## Project Management & Commitments

| Element | Description | Provider Details | Change from Baseline |
|---|---|---|---|
| Expendable Launch Vehicle | Deliver the spacecraft to operational orbit | Provider: Orbital-ATK<br>Lead Center: KSC<br>Performing Center(s): KSC<br>Cost Share Partner(s): n/a | N/A |
| Spacecraft | Transport instruments to science destination | Provider: Orbital ATK<br>Lead Center: N/A<br>Performing Center(s): N/A<br>Cost Share Partner(s): n/a | N/A |
| MIGHTI | High resolution imager instrument | Provider: Naval Research Laboratory<br>Lead Center: N/A<br>Performing Center(s): N/A<br>Cost Share Partner(s): | N/A |
| EUV | Extreme UV instrument | Provider: University of California, Berkeley<br>Lead Center: N/A<br>Performing Center(s): N/A<br>Cost Share Partner(s): | N/A |
| FUV | Far UV instrument | Provider: University of California, Berkeley<br>Lead Center: N/A<br>Performing Center(s): N/A<br>Cost Share Partner(s): Belgian Centre Spatial de Liège (CSL) | N/A |
| IVM | Ion velocity meter instrument | Provider: University of Texas, Dallas<br>Lead Center: N/A<br>Performing Center(s): N/A<br>Cost Share Partner(s): | N/A |

# IONOSPHERIC CONNECTION EXPLORER (ICON)

| Formulation | Development | Operations |
|---|---|---|

## Project Risks

| Risk Statement | Mitigation |
|---|---|
| If: Only one Instrument Control Package (ICP) Engineering Model (EM) available to three instruments<br>Then: EM availability may negatively affect the instrument schedules. | Develop and track schedule for ICP EM echo usage. |

## Acquisition Strategy

All acquisitions are in place. NASA selected ICON through the AO two-step process, and awarded the science investigation to the University of California Berkeley PI in April 2013.

### MAJOR CONTRACTS/AWARDS

NASA awarded the mission Phase B through F (formulation through operations and closeout) procurement to the University of California at Berkeley for the PI-controlled mission. All major contracts are in place.

| Element | Vendor | Location (of work performance) |
|---|---|---|
| FUV and EUV instruments | University of California, Berkeley | Berkeley, CA |
| MIGHTI instrument | Naval Research Laboratory | Washington, DC |
| IVM instrument | University of Texas, Dallas | Dallas, TX |
| Spacecraft, I&T | Orbital Sciences Corporation | Dulles, VA |
| Payload integration | Space Dynamics Laboratory | Logan, UT |
| Launch Vehicle | KSC | KSC, FL |

### INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | SRB | Jan 2014 | SRR to evaluate ICON requirements | Successful | Jul 2014 |
| Perform-ance | SRB | Jul 2014 | PDR to assess readiness for KDP-C | Successful | Apr 2015 |

# IONOSPHERIC CONNECTION EXPLORER (ICON)

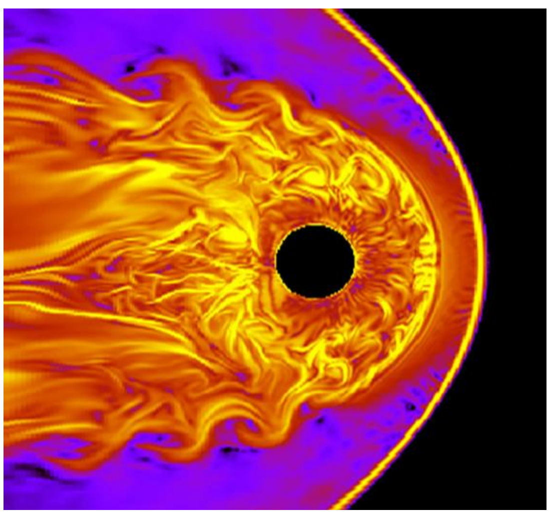
| Formulation | Development | Operations |
|---|---|---|

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | SRB | Apr 2015 | Critical Design Review to assess readiness for KDP-D | Successful | Aug 2016 |
| Perform-ance | SRB | Aug 2016 | Mission Pre-Environmental Review | | Jan 2017 |
| Perform-ance | SRB | Jan 2017 | Observatory Pre-Ship Review | | May 2017 |

# OTHER MISSIONS AND DATA ANALYSIS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Global-scale Observations of the Limb and Disk (GOLD) | 13.9 | -- | **16.3** | 8.6 | 4.6 | 2.0 | 0.0 |
| Heliophysics Explorer Future Missions | 0.0 | -- | **3.3** | 8.5 | 74.5 | 149.3 | 156.1 |
| Heliophysics Explorer Program Management | 8.5 | -- | **10.4** | 4.8 | 8.8 | 8.3 | 5.0 |
| Interface Region Imaging Spectograph (IRIS) | 8.2 | -- | **7.7** | 6.8 | 7.0 | 6.5 | 6.5 |
| Interstellar Boundary Explorer (IBEX) | 3.4 | -- | **3.4** | 3.3 | 3.4 | 3.4 | 3.4 |
| TWINS | 0.6 | -- | **0.6** | 0.6 | 0.6 | 0.6 | 0.6 |
| CINDI | 1.2 | -- | **0.3** | 0.2 | 0.0 | 0.0 | 0.0 |
| Aeronomy of Ice in Mesophere (SMEX-9) | 3.0 | -- | **3.0** | 2.9 | 3.0 | 3.0 | 3.0 |
| Time History of Events and Macroscale Interactions during Substorms (THEMIS) | 5.4 | -- | **5.4** | 5.0 | 5.1 | 4.5 | 4.5 |
| ACE | 3.0 | -- | **3.0** | 2.9 | 3.0 | 3.0 | 3.0 |
| RHESSI | 1.8 | -- | **1.9** | 1.9 | 1.9 | 1.9 | 1.9 |
| **Total Budget** | **48.9** | -- | **55.2** | **45.6** | **111.8** | **182.5** | **184.0** |



**Kelvin-Helmholtz waves have since been discovered all over the universe: in clouds, in the atmospheres of other planets, and on the sun. To spot the frequency of the Kelvin-Helmholtz waves, researchers used instrument data from two NASA spacecraft: the Advanced Composition Explorer (ACE) and the Time History of Events and Macroscale Interactions during Substorms (THEMIS). The magnetosphere simulation above shows, in color code, the electrical current density in the equatorial plane. The wavy region, when Earth's magnetic field interacts with the streaming solar wind, is the magnetopause.**

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

The Heliophysics Explorer Other Missions and Data Analysis budget includes operating Explorer missions, program management, and funding for the mission currently in the competitive principal investigator-led mission procurement cycle.

For more information, go to http://science.nasa.gov/about-us/smd-programs/explorers/.

## Mission Planning and Other Projects

### GLOBAL-SCALE OBSERVATIONS OF THE LIMB AND DISK (GOLD)

# OTHER MISSIONS AND DATA ANALYSIS

The GOLD investigation will perform unprecedented imaging of the Earth's thermosphere and ionosphere. For the first time, GOLD will answer fundamental scientific questions about how the thermosphere/ionosphere system responds to geomagnetic storms, solar radiation, and upward propagating waves and tides.

### Recent Achievements

GOLD has successfully completed KDP-C (Confirmation) in March 2015 and CDR in October 2015 and is proceeding towards Pre-Environmental Review with excellent technical progress.

## EXPLORER FUTURE MISSIONS

Explorer Future Missions provides the resources required to manage the planning, formulation, and implementation of all Explorer missions. The program office ensures successful achievement of Explorer program cost and schedule goals, while managing cross-project dependencies, risks, issues, and requirements as projects progress through formal key decision points. Additionally, Future Missions supports the Explorer procurement activities, including the pre-formulation activities for missions not yet approved as projects.

## EXPLORER PROGRAM MANAGEMENT

Explorer Program Management encompasses the program office resources required to manage the formulation and implementation of all Explorer projects. The program office is responsible for providing support and guidance to projects in resolving technical and programmatic issues and risks, for monitoring and reporting technical and programmatic progress of the projects and for achieving Explorer cost, schedule, and technical goals and requirements.

### Recent Achievements

The Explorer Program Office successfully completed the Heliophysics Program Implementation Review in November 2014. This review is an independent assessment that validates the strategic direction and implementation of the Explorer, STP, and LWS flight programs.

# Operating Missions

## INTERFACE REGION IMAGING SPECTROGRAPH (IRIS)

IRIS is a Small Explorer mission selected in June 2009 and launched on June 27, 2013. IRIS joined a network of solar spacecraft and ground-based observatories to provide unprecedented insight into a little understood region of the Sun called the interface region. IRIS is enabling scientists to understand what energizes the solar atmosphere, providing significant new information to increase our understanding of energy transport into the corona and solar wind, which provides a model for all stellar atmospheres. The mission will extend the scientific output of existing heliophysics spacecraft that follow the effects of energy release processes from the Sun to Earth. IRIS provides key insights into all these processes, and thereby advances our understanding of the solar drivers of space weather from the corona to the far heliosphere by combining high-resolution imaging and spectroscopy for the entire chromosphere and adjacent regions.

### Recent Achievements

IRIS has provided scientists with five new findings into how the Sun's atmosphere, or corona, is heated far hotter than its surface, what causes the Sun's constant outflow of particles called the solar wind, and what mechanisms accelerate particles that power solar flares. The first result identified heat pockets of 200,000 degrees Fahrenheit lower in the solar atmosphere than ever observed by previous spacecraft. Scientists refer to the pockets as solar heat bombs because of the amount of energy they release in such a short time. For its second finding, IRIS observed numerous small low-lying loops of solar material in the interface region for the first time. A surprise to researchers was the third finding of IRIS observations showing structures resembling mini-tornadoes occurring in solar active regions for the first time. These tornadoes move at speeds as fast as 12 miles per second and are scattered throughout the chromosphere, the layer of the Sun in the interface region just above the surface. They provide a mechanism for transferring energy to power the million-degree temperatures in the corona. Another finding uncovers evidence of high-speed jets at the root of the solar wind. The jets are fountains of plasma that shoot out of coronal holes, areas of less dense material in the solar atmosphere, and may be a source of the solar wind. The result highlights the effects of nanoflares throughout the corona. A mechanism called magnetic reconnection, whereby magnetic field lines cross and explosively realign, initiates large solar flares. These often send particles out into space at nearly the speed of light. One theory espouses that smaller versions of these, called nanoflares, drives coronal heating. IRIS observations show high-energy particles generated by individual nanoflare events affecting the chromosphere for the first time. These findings reveal a region of the Sun more complicated than previously thought. Combining IRIS data with observations from other Heliophysics missions is enabling breakthroughs in our understanding of the Sun and its interactions with the solar system.

## INTERSTELLAR BOUNDARY EXPLORER (IBEX)

IBEX is the first mission designed to image the edge of the solar system. As the solar wind from the Sun flows out beyond Neptune, it collides with the material between the stars, forming several boundaries. These interactions create energetic neutral atoms, particles with no charge that move very quickly. This region emits no light that conventional telescopes can see, so IBEX measures the particles that happen to be traveling inward from the boundary instead. IBEX contains two detectors designed to collect and measure energetic neutral atoms, providing data about the mass, direction of origin, and energy of these particles. From these data, researchers create maps of the boundary. The mission's focused science objective is to discover the nature of the interactions between the solar wind and the interstellar medium at the edge of the solar system. This region is important because it shields a large percentage of harmful galactic cosmic rays from Earth and the inner solar system.

### Recent Achievements

In 14 papers published in the October 2015 Astrophysical Journal Supplement, scientists present findings from NASA's IBEX mission providing the most definitive analyses, theories and results about local interstellar space to date. IBEX uses energetic neutral atom imaging to examine how our heliosphere, the magnetic bubble in which our Sun and planets reside, interacts with interstellar space. IBEX created the first global maps of these interactions and how they change over time. IBEX also directly measures interstellar neutral atoms flowing into the solar system; the journal's special issue focuses on these particles. Eight papers highlight the interstellar helium measurements taken by IBEX and the joint ESA and NASA Ulysses spacecraft, which launched in 1990. These are the only two spacecraft to have directly measured the local interstellar flow of these helium atoms. The studies resolved an inconsistency in the direction and temperature of the interstellar flow in the data gathered by Ulysses compared to those taken by IBEX. Both data sets now affirm that the local interstellar flow is significantly hotter than believed previously based on the Ulysses observations alone, and provide insight into the direction the heliosphere is moving through the local material in the galaxy, as well as how fast it is traveling. Two papers examine aspects of determining the composition of interstellar particles, looking closely at oxygen, helium, and neon, as well as how those and other particles are effectively measured. The final four papers discuss analysis techniques and related theoretical considerations.

## Two Wide-Angle Imaging Neutral Atom Spectrometers (TWINS)

TWINS provides stereo imaging of Earth's magnetosphere, the region surrounding the planet controlled by its magnetic field that contains the Van Allen radiation belts and other energetic charged particles. TWINS gives a three-dimensional global visualization of this region, which has led to a greatly enhanced understanding of the connections between different regions of the magnetosphere and their relation to solar variability. TWINS is a NASA-sponsored mission of opportunity that has been operational since 2008 and approved for extended operations until September 2016.

### Recent Achievements

The TWINS mission has performed the first multi-scale study of medium-energy hydrogen and oxygen ion composition in the magnetosphere, demonstrating our ability to map the structure from the largest to the smallest spatial scale. The combination of TWINS images with local ion measurements by the Van Allen Probes provides complementary views of two different spatial scales. The Van Allen Probes mission provides detailed localized measurement, and the TWINS mission captures a global view.

## The Coupled Ion-Neutral Dynamics Investigations (CINDI)

CINDI is a mission to understand the dynamics of Earth's ionosphere. This mission studies the behavior of equatorial ionospheric irregularities, which can cause disruptions in communications and navigation systems. CINDI data incorporated into state-of-the-art physics models is leading to advances in specification and prediction of space weather events. CINDI is in extended phase until September 2016. The mission consists of two instruments on the Communication/Navigation Outage Forecast System (C/NOFS) satellite, a project of the U.S. Air Force.

### Recent Achievements

CINDI observations demonstrate a new predictive capability for the equatorial plasma structure in the Earth's upper atmosphere. The occurrence probability of plasma structures in the equatorial ionosphere and their relationship to the vertical drift observed near sunset just prior to their occurrence shows a remarkable continuous probability distribution, allowing specific predictions on key structures called ionospheric irregularities.

# OTHER MISSIONS AND DATA ANALYSIS

## AERONOMY OF ICE IN THE MESOSPHERE (AIM)

The Aeronomy of Ice in the Mesosphere is a mission to determine why polar mesospheric clouds form, and why they vary. Polar mesospheric clouds, Earth's highest-altitude clouds, form each summer in the coldest part of the atmosphere about 50 miles above the polar regions. These clouds are of particular interest, as the number of clouds in the middle atmosphere, or mesosphere, over Earth's poles has been increasing over recent years, possibly related to climate change. The spacecraft launched on April 25, 2007, completed its prime mission in FY 2009, and is currently in extended phase until September 2016.

### Recent Achievements

The AIM satellite has observed the largest extremes in planetary wave activity since the beginning of space based observations of the stratosphere in 1978 and they appear to be occurring more frequently prompting speculation that the atmosphere is changing. Data from the AIM explorer have shown how the temperature and humidity of the mesosphere can change dramatically from one year to the next. In some years, conditions remain relatively warm and dry until June; in others, cold and wet conditions cause polar mesospheric clouds to form by the first half of May. Winter-to-summer transitions in the underlying stratospheric winds explain the observed variations. In recent years, this stratospheric transition has shown unusual variability whereby in different years the transition occurs anytime from early spring to late spring. The physical mechanism that links this stratospheric variability with polar mesospheric cloud onset is planetary scale waves acting on the stratospheric polar vortex. The first six springs observed by AIM (2008-2013) have shown some of the largest variations in atmospheric dynamics since space-based observations began.

## TIME HISTORY OF EVENTS AND MACROSCALE INTERACTIONS DURING SUBSTORMS (THEMIS)

THEMIS is a Medium Class Explorers mission that launched on February 17, 2007, and is currently operating in extended phase until September 2016. Starting as a five-spacecraft mission, the three inner probes of THEMIS now focus on collecting data related to the onset and evolution of magnetospheric substorms, while the two outer probes (now referred to as ARTEMIS) have been repositioned into lunar orbits. Magnetospheric substorms are the explosive release of stored energy within the near-Earth space environment that can lead to space weather effects. The two ARTEMIS probes orbit the Moon's surface at approximately one hundred miles altitude and provide new information about the Moon's internal structure and its atmosphere. ARTEMIS provides two-point observations essential to characterizing the Moon's plasma environment and hazardous lunar radiation. THEMIS and ARTEMIS, among others in the Heliophysics portfolio, are examples of missions offering important dynamics knowledge useful for future human spaceflight.

### Recent Achievements

At times, the solar wind can enter near-Earth space if the solar magnetic field connects with Earth's magnetic field. THEMIS observations yield key discoveries regarding the entry mechanisms. KH waves, created at the boundary between two oppositely flowing fluids, occur in many physical systems. The KH waves form as the solar wind flows around the Earth's magnetosphere, allowing a mixing of solar wind plasma across this surface. To determine the frequency of the KH waves in near-Earth space, scientists used data from two NASA Heliophysics spacecraft: ACE and THEMIS. While scientists have occasionally spotted KH waves at this boundary before, they have found that the waves are much more

# OTHER MISSIONS AND DATA ANALYSIS

common than expected and may have more of an effect on our space environment than previously realized.

## ADVANCED COMPOSITION EXPLORER (ACE)

ACE observes particles of solar, interplanetary, interstellar, and galactic origins as they pass by its location near the L1 Lagrangian point, located about a million miles from Earth toward the Sun. Changing conditions over the solar cycle are presenting new opportunities, including providing new insights relevant to space weather events.

### Recent Achievements

Solar energetic protons are of major concern for human space exploration due to their sudden appearance coupled with their potential to increase human exposure to radiation dose. The ACE spacecraft has highly sophisticated instrumentation for detecting many particle species emitted by the Sun in energetic particle events. New research exploits a combination of channels of the Electron, Proton, and Alpha Monitor instrument to measure energetic protons for the first time. The identification of these super-fast protons can improve the timing of particle acceleration and release from near the Sun, and thus help narrow down the candidates of particle acceleration, a major objective of the Heliophysics research program.

## RAMATY HIGH ENERGY SOLAR SPECTROSCOPIC IMAGER (RHESSI)

The RHESSI satellite focuses on the highest energy X-rays and gamma rays produced by the Sun, helping to observe solar flares of all shapes and sizes.

### Recent Achievements

Radio observations are an ideal complement to RHESSI hard X-ray flare observations since they provide physically distinct perspectives on energetic electrons, hot plasma, and the magnetic field. Combining X-ray and radio observations at different wavelengths leads to important new diagnostics. Of the many types of radio bursts, decametric spike bursts are of particular interest because scientists believe them to be a direct radio signature of the acceleration process itself. Combined RHESSI and Very Large Array images reveal that these bursts are indeed at the same location as the hard X-ray source in the corona, meaning the two sets of data can be used to investigate the same physical source. Furthermore, using the properties derived from RHESSI, we confirmed the radio source was indeed the fundamental plasma emission. .

# AERONAUTICS

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Airspace Operations and Safety Program | 154.0 | -- | **159.4** | 159.2 | 176.2 | 189.1 | 221.5 |
| Advanced Air Vehicles Program | 240.6 | -- | **298.6** | 277.4 | 308.8 | 311.6 | 312.6 |
| Integrated Aviation Systems Program | 150.0 | -- | **210.0** | 255.4 | 381.4 | 493.0 | 556.7 |
| Transformative Aero Concepts Program | 97.4 | -- | **122.3** | 154.4 | 193.8 | 179.7 | 196.2 |
| **Total Budget** | **642.0** | **640.0** | **790.4** | **846.4** | **1060.1** | **1173.3** | **1286.9** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

# AERONAUTICS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Airspace Operations and Safety Program | 154.0 | -- | **159.4** | 159.2 | 176.2 | 189.1 | 221.5 |
| Advanced Air Vehicles Program | 240.6 | -- | **298.6** | 277.4 | 308.8 | 311.6 | 312.6 |
| Integrated Aviation Systems Program | 150.0 | -- | **210.0** | 255.4 | 381.4 | 493.0 | 556.7 |
| Transformative Aero Concepts Program | 97.4 | -- | **122.3** | 154.4 | 193.8 | 179.7 | 196.2 |
| **Total Budget** | **642.0** | **640.0** | **790.4** | **846.4** | **1060.1** | **1173.3** | **1286.9** |
| Change from FY 2016 | | | **150.4** | | | | |
| Percentage change from FY 2016 | | | **23.5%** | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

**NASA Aeronautics researches technologies and develops game-changing concepts for advanced aircraft.)**

An efficient and effective transportation system is fundamental to the future of our economy and is inextricably tied to a clean energy future. Aviation is a highly visible and forward-looking component of transportation. Aviation moves the world, and the U.S. is a global leader in aviation technology.

Aviation accounts for more than $1.5 trillion annually of total U.S. economic activity and is one of the few industries that generates a positive trade balance: $78 billion in 2014, alone[1] . The aviation industry supports more than 11.8 million direct and indirect jobs, including more than one million high-quality manufacturing jobs[2].

Through NASA, the U.S. government has for decades had a highly productive partnership with the U.S. aviation industry and the nation's foremost universities leading to breakthroughs that have improved the efficiency, performance, and safety of aviation for all citizens. For example, the FY 2015 completion of the Environmentally Responsible Aviation (ERA) project demonstrates the potential impact of NASA Aeronautics research – estimates for potential fuel savings through the application of ERA technologies through 2050 could approach 80 billion gallons.

[1] "Bureau of Transportation Statistics http://www.transtats.bts.gov/Data_Elements.aspx?Data=2
[2] "The Economic Impact of Civil Aviation on the U.S. Economy," FAA June 2014

# AERONAUTICS

Today, we stand on the cusp of the next era in aviation. Recent technology advances in many different fields are coming together to enable breakthroughs in the speed and efficiency of transport aircraft that are the backbone of the aviation system. These breakthroughs will also enable new markets for smaller aircraft, from unmanned aircraft systems (UAS) that serve search and rescue, agriculture and commerce applications to the potential for new modes of personal transport. These innovations will support new jobs, new opportunities, and new ways for the U.S. to lead the world in technology and innovation.

To ensure research focus on enabling the next era in aviation, NASA Aeronautics guides its efforts with its visionary strategic implementation plan (http://www.aeronautics.nasa.gov/strategic-plan.htm). The plan lays out NASA's approach to addressing growing demand for global air mobility, the major challenges of energy efficiency and environmental sustainability, and the opportunity for convergence between traditional aeronautical disciplines and technology advances in information, communications, energy and other rapidly evolving technologies. The strategic implementation plan (SIP) identifies six research thrusts:

- Thrust 1: Safe, efficient growth in global operations;
- Thrust 2: Innovation in commercial supersonic aircraft;
- Thrust 3: Ultra-efficient commercial vehicles;
- Thrust 4: Transition to low-carbon propulsion;
- Thrust 5: Real-time, system-wide safety assurance; and
- Thrust 6: Assured autonomy for aviation transformation

NASA has an investment strategy supporting long-term research roadmaps to enable major outcomes in each of these thrusts. The roadmaps are implemented in partnership with the aviation community and reflect visionary solutions to aviation system needs that will ensure major benefits in mobility, environmental sustainability, and safety, while ensuring continued long-term aviation technology leadership in this rapidly expanding global industry.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| Mandatory Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 | Outyears |
|---|---|---|---|---|---|---|---|---|
| **21st Century Clean Transportation Plan** | -- | -- | **100.0** | **200.0** | **400.0** | **500.0** | **600.0** | **1900.0** |
| *Airspace Operations and Safety Program* | | | *18.0* | *20.0* | *35.0* | *45.0* | *75.0* | **170** |
| *Advanced Air Vehicles Program* | | | *30.0* | *41.0* | *79.0* | *80.0* | *65.0* | **305** |
| *Integrated Aviation Systems Program* | | | *37.0* | *84.0* | *196.0* | *300.0* | *370.0* | **1170** |
| *Transformative Aero Concepts Program* | | | *15.0* | *55.0* | *90.0* | *75.0* | *90.0* | **255** |
| **Low Boom Flight Demonstrator** | | | **55.9** | | | | | |
| *Integrated Aviation Systems Program* | | | *55.9* | | | | | |

With this request, NASA Aeronautics begins a major new initiative, New Aviation Horizons (NAH), which is a bold series of experimental aircraft and systems demonstrations to advance the NASA Aeronautics strategic vision in partnership with the aviation community. This NAH initiative demonstrates and validates transformative concepts with integrated, advanced technologies to meet the long term needs of aviation and sustain U.S. technological leadership. In FY 2017, NASA will initiate an NAH - Subsonic Demonstrator project to design and build advanced configuration subsonic transport X-planes that demonstrate and validate the configurations and technologies to achieve a 50 percent reduction in fuel use while also dramatically reducing noise. NAH is led by the Integrated Aviation Systems Program (IASP) and supports the achievement of all six research thrusts over time. The NAH initiative is built upon advancements in concepts and technologies that NASA Aeronautics has pioneered in partnership with industry and universities over the past decade.

With the request, NASA will also establish the Hypersonics Technology (HT) Project. NASA will balance investments that support and leverage the work of the Department of Defense (DoD) with investments in fundamental hypersonics research.

With mandatory funds in FY2017, NASA will initiate an NAH - Low Boom Flight Demonstrator (LBFD) project to demonstrate quieter supersonic flight. Over the past decade, fundamental research and experimentation has demonstrated the possibility of supersonic flight with much reduced sonic boom noise. The low boom X-plane will demonstrate these advancements in flight utilizing a purpose-built experimental aircraft, supporting the development of a sonic boom standard that would allow overland commercial supersonic flight (currently prohibited). Preliminary design review for the LBFD will be completed in FY 2016, and detailed design will begin in FY 2017.

## 21st Century Clean Transportation Plan

In FY 2017, NASA Aeronautics programs are supported in part by mandatory funding including funding from the 21st Century Clean Transportation Plan. This plan extends beyond the five-year period covered in this document. Full funding for the plan in Aeronautics is $3.7 billion over 10 years.

The 21st Century Clean Transportation Plan accelerates aviation energy efficiency, propulsion system transformation, and major improvements in aviation mobility. With this additional funding, NASA will accelerate and expand the NAH - Subsonic Demonstrator project to evaluate advanced configuration subsonic transport X-planes. In FY 2017, NAH will initiate the development of a formal preliminary design for a large-scale Hybrid Wing Body (HWB) experimental aircraft. The HWB configuration has been the focus of substantial research and experimentation and represents the most mature concept, ready for flight demonstration and validation.

NAH will also develop a series of transformative hybrid electric propulsion demonstrators, starting at small scale for risk reduction, learning, and for early applications, and then transitioning to a larger scale X-Plane demonstration focused on propulsion innovation for subsonic transport class aircraft. Hybrid electric propulsion is a very promising technology pathway that is in its initial stages. The promise is substantially reduced emissions, while also enabling significant improvements in fuel efficiency from innovative vehicle-propulsion integration. This series of demonstrators, which will begin after the initial subsonic transport X-planes are underway, will enable the aviation community to collaborate in exploring the many technical issues that must be addressed to enable such a transformation in aviation.

With additional funding, NASA will accelerate and expand the scope NAH-LBFD project to include the use of low carbon alternative fuels. The NAH-LBFD flight tests will demonstrate the promise of both the long-term improvement in global mobility from supersonic flight, while also ensuring low environmental impact consistent with the 21st Century Clean Transportation Plan.

Taken together, the NAH demonstrations accelerate aviation to a high efficiency, high mobility, and low emissions future, while ensuring the next generation of U.S. technological leadership for a growing aviation demands.

In addition to NAH, additional efforts will be phased in over the next several fiscal years, including increased investment in enabling tools and technologies, revolutionizing operational efficiency, fostering advanced concepts and training the future workforce, and leveraging non-aerospace technology advancements. In the category of enabling tools and technologies, one element is ground testing of advanced technologies that reduce the risk of application in NAH demonstrators. Another element is a major research effort to enable smaller engine cores for turbofan engines leading to higher bypass, higher efficiency engines. Smaller engine cores are also enabling for hybrid electric propulsion systems. Additionally, accelerated research on robust, fuel flexible combustors enables higher fractions of low-carbon alternative fuel utilization. Finally, fully funding the Computational Fluid Dynamics (CFD) 2030 plan delivers highly advanced physics-based flow simulations that enable confident design of the advanced configurations being tested in NAH.

NASA will increase funding to revolutionize operational efficiency by developing and demonstrating gate-to-gate Trajectory Based Operations (TBO) capabilities, building on the great success of the Air Traffic Management (ATM) Technology Demonstrations (ATDs) that have been performed in partnership with the Federal Aviation Administration (FAA) and industry. Current ATDs coupled with TBO demonstration and validation will enable the full Next Generation Air Transportation System (NextGen) vision, maximizing operational efficiency and reducing energy consumption.

NASA will augment internal early stage innovative research and the new university leadership initiative to focus on high efficiency, low carbon concepts, fostering advanced concepts and training the future workforce. Empowering NASA’s creative research workforce and the university community, including the brightest young minds in the nation, excited about clean and innovative aviation systems, will propel future advancements in ways that cannot be anticipated today.

Finally, NASA will leverage non-aerospace technology advancements through support of challenge prizes to bring key non-aerospace technologies, such as advanced energy storage technologies, into aeronautics applications. These challenge prizes will add another element of broad innovation to complement accelerated advancements in aviation.

The suite of investments that comprise the 21st Century Clean Transportation Plan is fundamentally aligned to the achievement of the NASA Aeronautics SIP. The investments provide a balanced approach to achieving a major acceleration of aviation efficiency improvements and emissions reductions, while creating a pipeline of new ideas and new engineers capable of continued progress in transforming aviation.

## ACHIEVEMENTS IN FY 2015

### Thrust 1: Safe, efficient growth in global operations

NASA continued to make significant progress in developing automation that enables the success of the Nation's NextGen initiative, in partnership with FAA and industry, supporting the TBO capability. NASA delivered the final technology transfer associated with Terminal Sequencing and Spacing (TSAS) to the FAA NextGen Office. TSAS technology (the ground-based portion of the ATD-1 activity) provides information to air traffic controllers about the aircraft speeds and spacing that enable approaches into airports reducing flight delays saving time and reducing fuel consumption. In cooperation with the FAA, NASA tested TSAS prototype software as integrated with operational versions of FAA hardware to reduce deployment risk. NASA also prepared for extensive testing of the Spot and Runway Departure Advisor (SARDA) in operational field trials at the American Airlines Ramp Tower at Charlotte Douglas International Airport. SARDA improves tower controller's ability to direct airport surface operations efficiently by allowing non-stop, continuous movement of aircraft on taxiways resulting benefits of increased throughput and reduced fuel consumption. NASA conducted live data interface and extensive shadow testing of the SARDA system and underwent a follow-on human-in-the-loop (HITL) simulation to address gaps discovered in the shadow testing.

### Thrust 2: Innovation in commercial supersonic aircraft

NASA's progress in low-noise commercial supersonic flight continued to advance the nation's readiness for experimental flight demonstration of this capability. NASA completed experimental and analytical studies of jet engine exhaust and studies of the interactions of the exhaust with shock waves generated in supersonic flight. Specifically, NASA performed assessments of exhaust effects utilizing CFD analysis with comparison to experimental test data from the NASA Glenn Research Center (GRC) 1x1-Foot Supersonic Wind Tunnel. Understanding these jet engine exhaust effects were the final step needed to develop a first-of its kind set of low sonic boom aircraft design tools that NASA made available to industry. These unique tools enable aircraft design engineers to rapidly design vehicles with low sonic boom noise signatures that provide industry the ability to confidently design new supersonic commercial aircraft.

### Thrust 3: Ultra-efficient commercial vehicles

The completion of NASA's ERA Project represents a major milestone for the aviation industry in supporting development of the next generation of ultra-efficient subsonic transports. NASA's ERA Project, during its final year, matured and demonstrated several high impact technologies in relevant environments. Specifically, the ERA project successfully completed eight Integrated Technology Demonstrations, which together could reduce fuel burn by 50 percent, community noise by 42 decibels below stage 4 noise standards, and nitrogen oxides emission by 75 percent during take-off and landing. The U.S. aviation industry coordinated and collaborated with NASA's ERA project through cost-sharing partnerships throughout its project life, ensuring industry can confidently and efficiently integrate these technologies into future generations of transport aircraft. The net effect of the application of these technologies through mid-century is measured in tens of billions of gallons of fuel savings, reducing the cost of air travel and substantially reducing environmental impacts.

### Thrust 4: Transition to low-carbon propulsion

NASA completed analysis, documentation, and dissemination of test results from a flight campaign to characterize the gaseous and particulate cruise emissions of biofuel-blended jet fuels and effects of fuel sulfur during flight at cruise conditions. This effort is part of a multi-agency and aviation community-wide effort to enable the greater use of drop-in alternative fuels for aviation. This internationally recognized data set (at https://aero-fp.larc.nasa.gov/) enables the atmospheric science community to continue to improve emissions modeling and guides the development of international standards for aircraft emissions when drop-in alternative fuels are used.

### Thrust 5: Real-time, system-wide safety assurance

NASA continued research aimed at improving methods for ensuring aviation safety. NASA delivered two guidance documents to the FAA that provide recommendations for increasingly efficient and effective assurance of future complex aviation systems. The first document addresses the development of modern systems by multi-tier networks of suppliers and identifies gaps in the processes intended to ensure safety and regulatory compliance. Recommendations for short-term and long-term solutions to achieving a higher level of confidence in the design of complex avionics systems are presented, including suggestions for new and revised guidelines. The second document provides guidance on new approaches to software assurance for the FAA. Current methods are less efficient than desired, creating a barrier to the rapid introduction of new aviation systems. The report provides information on alternative approaches to software assurance as well as case studies. NASA also made progress toward system-wide availability of our safety analysis tools, already in use by some U.S. Airlines, by working with the FAA and Aviation Safety Information and Sharing System (ASIAS) to validate use of NASA tools on their safety data.

### Thrust 6: Assured autonomy for aviation transformation

NASA continued to lead the U.S. in researching the key issues for safe UAS operations. NASA delivered data, analyses, and recommendations to support the Radio Technical Commission for Aeronautics' (RTCA) Special Committee on UAS Integration into the NAS (SC 228) in their effort to set preliminary Minimum Operational Performance Standards (MOPS). The special committee is responsible for developing the MOPS required for flying UAS in the NAS. NASA based its recommendations on a series of simulations and flight tests that included an integrated flight test series using simulated airspace/traffic with a live test vehicle. NASA’s contribution included guidance, alerting, human machine interface, aircraft performance, terminology, system specific performance requirements, and equipment test procedures. This information is a part of the approved RTCA Program Management Council’s Preliminary MOPS

## WORK IN PROGRESS IN FY 2016

### Thrust 1: Safe, efficient growth in global operations

NASA will continue to make significant progress in developing automation that enables the success of the Nation’s NextGen initiative, in partnership with FAA and industry, as well as deliver solutions to critical aviation safety issues. NASA will continue development of an integrated set of NextGen tools and technologies, known as Interval Management - Terminal Area Precision Scheduling and Spacing technologies or Air Traffic Management Technology Demonstration 1 (ATD-1), that provide an efficient arrival solution for managing aircraft beginning from just prior to top-of-descent and continuing down to the runway. This will demonstrate throughput and delay benefits, and minimize fuel burn, noise, and greenhouse gas emissions for arrival operations during peak traffic conditions in the terminal area. NASA is working with the FAA, airlines, aircraft, and avionics manufacturers, ground-based automation system integrators, and airports to prepare to test this integrated set of technologies at a dense terminal of a busy commercial airport by 2017. NASA will also develop tools to reduce take-off time variances. These tools will increase predictability of the airspace system and allow airlines to reduce schedule block-times for flights during high-demand periods. It supports the Integrated Arrival/Departure/Surface (IADS) (also known as ATD-2) concept of operations. This will result in significant cost reduction to airlines, and reduce emissions and fuel burn. After over two years of extensive HITL simulations of the SARDA system in operational scenarios, NASA will evaluate this tool in operational training, shadow testing and live traffic evaluations throughout FY 2016. The evaluations will culminate in a technology licensing and transfer to airlines by early FY 2017. These described automaton tools serve as fundamental building blocks for gate-to-gate TBO capability.

In addition, NASA continues to address key safety issues to ensure safe operations. NASA will complete studies to determine the most promising super-cooled large droplet (SLD) icing (i.e. freezing drizzle and rain) experimental simulation methods. The ability to provide an SLD freezing drizzle/rain environment in a ground test facility will allow for the efficient and effective testing of aircraft components, computer simulation validations and SLD freezing drizzle/rain protection systems. The ability to provide an SLD freezing drizzle/rain environment in a ground test facility does not currently exist, and future air vehicles will need to operate safely under SLD-like conditions.

### Thrust 2: Innovation in commercial supersonic aircraft

NASA will achieve a major milestone in enabling development of low noise commercial supersonic aircraft by completing the Low Noise Propulsion for Low-Boom Aircraft technical challenge. This technical challenge addresses the development of computer-based design tools and innovative concepts for integrated low-noise supersonic propulsion systems and demonstrates these concepts through ground testing. Although overcoming the barrier of sonic boom noise is a primary focus in this Thrust, this research effort recognizes that future commercial supersonic aircraft will have to be as quiet as possible to meet the same stringent airport noise regulations that govern the subsonic fleet. The planned activity addresses the challenge of designing low sonic boom noise aircraft that also meet the current airport noise requirement and anticipates an increase in the stringency of the noise requirement in the future. In addition, NASA will initiate and nearly complete a detailed preliminary design for a low boom demonstrator aircraft. This design will enable the development of an aircraft capable of generating the necessary data to support an overland boom standard for commercial supersonic flight.

### Thrust 3: Ultra-efficient commercial vehicles

NASA will continue to advance the technical readiness of the most promising advanced configurations for future subsonic transports. NASA will validate the high-speed performance and aerodynamic design of a Truss Braced Wing (TBW) aircraft conceptual design, as a viable technology to reduce transport aircraft fuel use. Using high fidelity, CFD-based aerodynamic methods, NASA will design the detailed novel aerodynamic shape of the configuration. One unique challenge for the TBW concept is the design of a low drag truss structure and its integration with the wing and fuselage. To validate the design and contribute to an update of the integrated system assessment of this TBW concept and to more completely assess an integrated TBW aircraft system, NASA will test a high-fidelity aerodynamic wind tunnel model in the 11x11-Foot Transonic Wind Tunnel at the NASA Ames Research Center (ARC). In addition, NASA will initiate at least three exploratory design studies for potential subsonic transport experimental aircraft that can demonstrate ultra-efficiency metrics and validate a suite of advanced technologies and methods.

### Thrust 4: Transition to low-carbon propulsion

NASA will perform disciplined technical exploration of new, revolutionary hybrid-electric propulsion concepts. Additionally, NASA will develop a detailed conceptual design of a hybrid gas-electric propulsion system for a transport-class aircraft and assess its overall vehicle-level benefits in terms of noise, emissions, and energy consumption. This detailed conceptual design will enable NASA to determine, prioritize, and accelerate research on the most critical technical challenges, including the key performance metrics.

### Thrust 5: Real-time, system-wide safety assurance

NASA will continue to develop safety analysis tools that represent progress toward real-time system-wide safety assurance while providing near-term benefits to the aviation safety community. Specifically, NASA will refine and extend the capabilities of specialized data analytics that identify anomalies and precursors to safety incidents using operational data. Initial efforts to increase the processing of this data will support development of a system to detect emerging risks in real-time and provide decision support for mitigation strategies. One real-time safety risk assessment tool, designed to monitor on-duty operator fatigue levels and validated in FY 2015, will be made publicly available. NASA will also continue efforts to push the evolution of safety assurance techniques for complex systems. Development of run-time monitoring capabilities for software and system assurance will enable progress toward continuous lifecycle assessment of aviation systems.

### Thrust 6: Assured autonomy for aviation transformation

NASA will continue to lead the U.S. in researching key issues for safe UAS operations. NASA will conduct two flight test series with simulated traffic and live vehicles that will demonstrate new technologies that allow safe UAS operation in the National Airspace System (NAS). This planned testing follows the flight test series conducted in FY 2015 and will be the final flight testing in the integrated campaign. The planned progression of this campaign tests higher levels of technology integration and higher complexity of test conditions. NASA will continue to support RTCA Special Committee on MOPS for UASes by providing final MOPS inputs based on the results of FY 2016 testing. These efforts are critical to the success of the RTCA Special Committee's effort and the standards necessary to achieve UAS integration into the National Airspace.

NASA will complete technical capability level (TCL) 1 under UAS Traffic Management (UTM) research. UTM is researching the requirements and capabilities to enable safe operation of small UAS at low altitude. Capabilities include initial trajectory management by offering geo-fencing, initial wind/weather integration, rules of the road, and procedural separation. UTM will utilize the integrated capabilities to demonstrate low-altitude operations of UAS with all other users. NASA will transition UTM TCL 1 to the FAA UAS test sites for demonstrations of initial concepts. This will allow a limited number of homogeneous vehicles to explore uses like search and rescue, agriculture applications, humanitarian, or science missions. Future TCLs planned through FY 2019 will add additional capabilities.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

### Thrust 1: Safe, efficient growth in global operations

NASA will continue to make significant progress in developing automation that enables the success of the Nation's NextGen initiative, in partnership with FAA and industry, and ultimately lead to gate-to-gate TBO capability. The development of ATD-1 flight-deck interval management technologies will culminate in flight test demonstrations planned for early FY 2017. NASA will install and evaluate prototype flight hardware and software based on an algorithm for Airborne Spacing for Terminal Arrival Routes. Upon successful integration of the systems in the demonstration, final analysis, documentation, and technology transfer to the FAA will occur late FY 2017. NASA will also conduct an ATD-2 Departure Metering demonstration at Charlotte Douglas International Airport, the test site for this initial simulation of a NextGen departure metering capability. This demonstration supports the FAA's joint government/industry initiative aimed at improving air traffic flow management through increased information exchange among airline and airport stakeholders.

### Thrust 2: Innovation in commercial supersonic aircraft

NASA will begin the NAH Initiative within IASP to develop and test experimental aircraft and systems. As part of this initiative, NASA will initiate the detailed design and build of the world's first LBFD. This demonstrator will be used to collect the flight data necessary to establish overland supersonic noise regulations. In support of the future LBFD flight experiments, NASA will complete development of an initial set of models for the prediction of the community response to noise created by the overflight of future supersonic commercial aircraft. Based on simulations conducted in NASA's Interior Effects Laboratory, the first of these models will be capable of predicting the response of a person who hears supersonic overflight noise while indoors. This model evaluates the level of noise required to prevent annoyance due to supersonic overflight. The second of these models will be able to predict the indoor noise created by supersonic overflight in a wide variety of homes with different room arrangements and construction techniques. With the combination of these models, NASA will begin analytical studies of community response to the overflight of future low noise supersonic commercial aircraft, enabling NASA to design the LBFD community overflight experiments.

### Thrust 3: Ultra-efficient commercial vehicles

The NAH initiative will also take the next steps on the development of a series of ultra-efficient subsonic transport (UEST) experimental aircraft. This builds off the overwhelming success of the ERA project and the multiple advanced configuration studies and experiments that have been performed over the past several years. In FY 2017, NASA will initiate the preliminary design for a large scale, fully integrated HWB experimental aircraft. The HWB is the most mature of the advanced concepts studied by NASA and various partners to date, and is ready for flight demonstration and concept validation. Preliminary Design Review (PDR) is targeted for FY 2018, with detailed design and build beginning in FY2019. NASA will also continue design studies with industry for future UEST experimental aircraft other than the HWB configuration that will emphasize other key technologies requiring flight demonstration and validation. Transition of these initial design studies to selection of UEST experimental aircraft for formal preliminary design will begin in FY 2018.

In support of the eventual development of UEST experimental aircraft, in FY 2017 NASA will test a revolutionary engine inlet-fan combination at the NASA GRC, through a NASA Research Announcement (NRA) with United Technologies Research Center (UTRC). The evaluation centers around the performance of this very promising, unique engine inlet-fan design for its vehicle-level fuel burn benefits at flight conditions that are typical of a modern transport aircraft. With this testing, NASA will complete a technical challenge related to understanding the interaction effects between engines and airframes for some advanced configurations relevant to a potential UEST experimental aircraft. In addition to this test, NASA will conduct other key high fidelity ground tests to further understand the potential of new configurations and reduce risks for UEST experimental aircraft.

### Thrust 4: Transition to low-carbon propulsion

NASA will accelerate research efforts to enable revolutionary hybrid-electric propulsion systems. NASA will conclude preparations for the testing of a superconducting motor. This motor test represents a major advancement in a key technology needed to realize practical larger-scale hybrid electric propulsion systems in the future. First flight of NASA's small scale distributed electric propulsion demonstrator aircraft will occur in FY 2017, demonstrating the efficiency benefits of the distributed integration of multiple smaller electric motors for small aircraft propulsion, and starting a research progression from smaller scale to larger scale experiments. The knowledge and experienced gained will complement and feed into NASA continued hybrid electric system concepts development.

### Thrust 5: Real-time, system-wide safety assurance

NASA will achieve a key milestone in enabling development of real-time, system-wide safety tools. In late FY 2017, the Beta build of the SMART-NAS Test Bed will deliver capabilities to (1) evaluate emergent air traffic behavior due to novel air traffic control concepts and (2) provide the FAA and airspace users the ability to evaluate mature concepts/technologies. Critical for development of a real-time safety system, the Test Bed will enable not only safety analysis for novel technologies but also testing and evaluation of tools that support a real-time system-wide safety capability. The Test Bed will be used to evaluate and refine data capture and fusion techniques, hazard identification and alerting using operational data, and decision support tools. By the end of FY 2017, matured hazard identification tools and initial decision support tools, featuring prognostic state awareness, will be ready for assessment in the Test Bed environment.

### Thrust 6: Assured autonomy for aviation transformation

NASA will continue to lead the U.S. in researching key issues for safe UAS operations. NASA will continue to develop and mature UTM technology to TCL 2, which will incorporate weather/wind integration, trajectory routing, object avoidance, and congestion management for operation of small UAS at low altitude in the first quarter of FY 2017. TCL 2 will leverage TCL1 results and focus on beyond-visual line-of-sight operations in sparsely populated areas. Researchers will test technologies that allow dynamic adjustments to user-requested flight plans based on availability of airspace and contingency management.

In addition, NASA will continue research focused on UAS integration by continuing to support the second phase of RTCA MOPS development. Initial research beginning in FY 2017 will focus on extended interoperability of manned and unmanned aircraft, satellite communications and advanced detect and avoid systems.

### Cross-Cutting Capabilities

NASA will complete design and installation of new acoustical treatment in the GRC 9x15-Foot Low Speed Wind Tunnel. This improvement will further reduce the facility background noise to levels that enable testing of next-generation low noise propulsion system concepts. Additionally, NASA will incorporate a new funding model for operation costs for NASA ground test facilities. To effectively develop technology and to validate and advance computational models, this particular model will recognize the value of ground testing to the fusion of experiments and numerical analysis. NASA will benefit from the additional facility utilization for program/project risk reduction and Center innovation initiatives. It will provide consistent usage, stewardship of ground test capabilities, and increased level of actual strategic investments to sustain and improve the portfolio of covered capabilities.

# Programs

## AIRSPACE OPERATIONS AND SAFETY PROGRAM

The Airspace Operations and Safety Program (AOSP) develops and explores fundamental concepts, algorithms, and technologies to increase throughput and efficiency of the NAS safely. The program works in close partnership with the FAA and the aviation community to enable and extend the benefits of NextGen, the Nation's program for modernizing and transforming the NAS to meet evolving user needs. Integrated demonstrations of these advanced technologies will lead to clean air transportation systems and gate-to-gate efficient flight trajectories. The program is on the leading edge of research into increasingly autonomous aviation systems, including innovation in the management of UAS traffic and other novel aviation vehicles and business models. The program is also pioneering the real-time integration and analysis of data to support system-wide safety assurance, enabling proactive and prognostic aviation safety assurance. The program takes lead responsibility for three of the Strategic Thrusts:

- Thrust 1: Safe, efficient growth in global operations;
- Thrust 5: Real-time, system-wide safety assurance; and
- Thrust 6: Assured autonomy for aviation transformation

## ADVANCED AIR VEHICLES PROGRAM

The Advanced Air Vehicles Program (AAVP) develops the tools, technologies, and concepts that enable new generations of civil aircraft that are safer, more highly energy efficient, and have a smaller environmental footprint. The program focus includes major leaps in the safety, efficiency, and environmental performance of subsonic fixed and rotary wing aircraft to meet challenging and growing long-term civil aviation needs; pioneering low-boom supersonic flight to achieve new levels of global mobility; and sustaining hypersonic competency for national needs while advancing fundamental hypersonics research. In partnership with academia, industry and other government agencies such as the FAA, AAVP pioneers fundamental research and matures the most promising technologies and concepts for transition to system application by the aviation industry. The program also works in partnership with the DoD to ensure both NASA and DoD vehicle-focused research is fully coordinated and leveraged. The program sustains and advances key national testing capabilities that support aeronautics research and development needs. The program takes lead responsibility for three of the Strategic Thrusts:

- Thrust 2: Innovation in commercial supersonic aircraft;
- Thrust 3: Ultra-efficient commercial vehicles; and,
- Thrust 4: Transition to low-carbon propulsion

## INTEGRATED AVIATION SYSTEMS PROGRAM

The Integrated Aviation Systems Program (IASP) focuses on experimental flight research and the spirit of integrated, technological risk taking that can demonstrate transformative innovation. Therefore, the program complements both AOSP and the AAVP by conducting research on the most promising concepts and technologies at an integrated system level. The program explores, assesses, and demonstrates the benefits of these potential technologies in a relevant environment. The program leads NASA Aeronautics' new NAH initiative. The program works in partnership with the other Aeronautics programs, other government agencies, academia, the aviation industry, and international partners as appropriate. The program supports the flight research and demonstration needs across all six Aeronautics Research Mission Directorate (ARMD) Strategic Thrusts.

## TRANSFORMATIVE AERONAUTICS CONCEPTS

The Transformative Aeronautics Concepts Program (TACP) cultivates multi-disciplinary, revolutionary concepts to enable aviation transformation and harnesses convergence in aeronautics and non-aeronautics technologies to create new opportunities in aviation. The program's goal is to demonstrate initial feasibility of internally and externally originated concepts to support the discovery and initial development of new, transformative solutions for all six ARMD Strategic Thrusts. Using sharply focused activities, the program provides flexibility for innovators to explore technology feasibility and provide the knowledge base for transformational aviation concepts. The program solicits and encourages revolutionary concepts, creates the environment for researchers to become immersed in trying out new ideas, performs ground and small-scale flight tests, allows failures and learns from them, and drives rapid turnover into new concepts. The program also supports research and development of major advancements in cross-cutting computational tools, methods, and single discipline technologies to advance the research capabilities of all Aeronautics programs.

# AIRSPACE OPERATIONS AND SAFETY PROGRAM

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **154.0** | **--** | **159.4** | **159.2** | **176.2** | **189.1** | **221.5** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*


**NASA's concept for a possible UTM system that would safely manage diverse UAS operations in the airspace above buildings and below crewed aircraft operations in suburban and urban areas.**

AOSP creates technologies that enable NextGen to fulfill its promise to transform the Nation's ATM systems. Moving key concepts and technologies from the laboratory into the field benefit the public ultimately by increasing capacity and reducing the total cost of air transportation. The current U.S. air transportation system is widely recognized to be among the safest in the world. Yet, while NextGen will meet this demand by enabling efficient passage through the increasingly crowded skies, it will come with increased operating complexity. Therefore, advanced automation technologies that work in harmony with human operators are critical for the United States to meet the public expectations for safety in this complex, dynamic domain.

NextGen technologies will also provide advanced levels of automated support to air navigation service providers and aircraft operators for reduced travel times and travel-related delays both on the ground and in the sky. These advanced technologies provide shortened routes for time and fuel savings, with associated improvements in noise and emissions, and permit controllers to monitor and manage aircraft for greater safety in all weather conditions.

AOSP, with the FAA and its other industry and academic partners, conceives, develops, and demonstrates NextGen technologies to improve the intrinsic safety of current and future aircraft that will operate in NextGen. To achieve and transition beyond the NextGen vision, the deployment of new operational concepts, capabilities, and twenty-first century technologies will be supported by the exploration and development of a test bed for safe global, gate-to-gate trajectory-based operations.

Current aviation and the ATM system face many challenges related to global competitiveness, efficiency, productivity, higher mobility needs, and emergence of newer airspace uses (such as commercial space launches, and unmanned aerial systems in low and high altitudes). NASA looks to ensure that the future airspace management system will accommodate these needs in an affordable manner for service providers, vehicle/platform operators, and passengers as well as cargo. NASA will conduct research and develop autonomous technologies for aircraft/platforms as well as managing the airspace to support diverse operations.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| Mandatory Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **21st Century Clean Transportation Plan** | **--** | **--** | **18.0** | **20.0** | **35.0** | **45.0** | **75.0** |

AOSP is supported in part by funding under a multiagency plan for a 21st Century Clean transportation Plan. This initiative extends beyond the five-year period covered in this document. Full funding for the initiative in AOSP is $0.4 billion over 10 years.

## ACHIEVEMENTS IN FY 2015

### Thrust 1: Safe, Efficient Growth in Global Operations

NASA delivered the final technology transfer associated with TSAS to the FAA NextGen Office. TSAS technology provides information to air traffic controllers about the aircraft speeds and spacing that enable clean and efficient approaches into airports. At the FAA's William J. Hughes Technical Center, NASA in cooperation with the FAA, tested Terminal Area Precision Scheduling and Spacing prototype software as integrated with operational versions of FAA hardware to reduce deployment risk. TSAS will reduce flight delays saving time and reducing fuel consumption.

NASA prepared for extensive testing of the SARDA in operational field trials at the American Airlines Ramp Tower at Charlotte Douglas International Airport. SARDA improves tower controller's ability to direct airport surface operations efficiently by allowing non-stop, continuous movement of aircraft on taxiways resulting in benefits of increased throughput and reduced fuel consumption. In the first half of FY 2015, NASA conducted live data interface and extensive shadow testing of the SARDA system to assess system robustness. In the second half of FY 2015, SARDA underwent a follow-on HITL simulation to address gaps discovered in the shadow testing.

### Thrust 5: Real-time, System-wide Safety Assurance

NASA delivered two reports to the FAA that addressed barriers to future systems safety assurance. The first addresses the issue of assuring the development of modern systems by a multi-tier network of suppliers, and identifies issues in the practice, regulation, policy, or guidance material relative to safety and regulatory compliance. Recommendations for short-term and long-term solutions to achieving a higher level of confidence in the design of complex computer-based aircraft systems will be included. The second report documented new approaches to software assurance for the FAA. The report outlined the results of a survey of alternative approaches to software assurance and knowledge obtained through preparation of a published guidebook considered the de facto standard for avionics equipment and software development worldwide.

AOSP identified alternative open architectures that will enable a plug-and-play capability of different technologies to operate in combined real, virtual, and constructive manners. These architectures support development of the Shadow Mode Assessment Using Realistic Technologies for the National Airspace System (SMART NAS) capability that will allow integrated, real-time, and/or fast-time assessment of gate-to-gate operations and their operational and safety performance using real-world NAS inputs.

### Thrust 6: Assured Autonomy for Aviation Transformation

Public attention to UASes and their growing presence in the NAS stimulated widespread interest in a conference co-hosted by NASA and held during July 2015 in California. The three-day UTM convention brought together a domestic and international audience of representatives from government and academia, as well as aviation, agriculture, film and other industries. Through discussions held at this conference, and with others, NASA continues development of a well-coordinated plan for researching and developing a UTM operational concept for low-altitude small UAS operations in the NAS that will inform regulatory actions taken in the future by the FAA.

In late August, NASA successfully completed an initial TCL 1 Demonstration flight test of a portable system that focuses on small UAS flying at low altitude. Objectives included demonstration of UTM capabilities/procedures, navigation performance, and aircraft tracking. The collected data included noise signatures, trajectory conformance, and observations for weather models. Analysis of the results will help design future UTM flight evaluations.

## WORK IN PROGRESS IN FY 2016

### Thrust 1: Safe, Efficient Growth in Global Operations

NASA will showcase an integrated set of NextGen tools and technologies that provide an efficient arrival solution for managing aircraft beginning from just prior to top-of-descent and continuing down to the runway. This demonstration known as Interval Management - Terminal Area Precision Scheduling and Spacing technologies or ATD-1 will integrate technologies that have been developed separately and each has shown throughput, delay, and/or fuel-efficiency benefits. Together, the technologies will demonstrate the feasibility of high throughput of efficient arrival operations during peak traffic conditions in the terminal area. The integration of these terminal arrival tools will allow arrival aircraft to safely fly closer together on more fuel-efficient routes to increase capacity, reduce delay, and minimize fuel burn, noise, and greenhouse gas emissions. NASA is working with the FAA, airlines, aircraft and avionics manufacturers, ground-based automation system integrators, and airports to test this integrated set of technologies. The benefits of these concepts will be demonstrated under the practical conditions of arriving flights at a dense terminal of a busy commercial airport. In addition, NASA will complete a sequence of integrated, high-fidelity simulations in preparation for field demonstrations of ATD-1 technologies by 2017.

AOSP is developing tools to reduce take-off time variances. These tools will increase predictability of the airspace system and allow airlines to reduce schedule block-times for flights during high-demand periods. This will result in significant cost reduction to airlines. Development of such advanced departure tools will include maturity assessment of candidate technologies that support the IADS (also known as ATD-2) concept of operations. This will include a schedule of simulations to support advancement of component technologies and their integration in addition to development of requirements, processes, and procedures.

After over two years of extensive HITL simulations of the SARDA system in operational scenarios, NASA will evaluate this tool in operational training, shadow testing and live traffic evaluations throughout FY 2016. The evaluations will culminate in a technology licensing and transfer to airlines by early FY 2017. These activities collectively deliver mature technologies that form the foundation for gate-to-gate TBO.

### Thrust 5: Real-time, System-wide Safety Assurance

AOSP will pursue improved operational safety by real-time system monitoring and assurance through development and refinement of specialized data analytics that identify anomalies in operational data and provide information about precursors to safety risks. Tools are scaled to analyze and incorporate data from multiple sources such as flight and radar track data, and written safety reports. Prognostic and decision-making tools will also be refined to support development of a system that can predict emerging risks and provide decision support for mitigation strategies. Development of run-time monitoring capabilities for software and system assurance will enable progress toward continuous lifecycle assessment of aviation systems.

### Thrust 6: Assured Autonomy for Aviation Transformation

NASA will complete the UTM TCL 1 to enable capability for safe operation of small UAS at low altitudes. The system will support the development of autonomous concepts, technologies, and procedures, and will demonstrate a prototype capability that enables operations of UAS while sharing airspace with other users. The TCL 1 system will include initial trajectory management by offering geo-fencing, initial wind/weather integration, rules of the road, and procedural separation. NASA will transition UTM TCL 1 to the FAA UAS test sites for demonstrations of initial concepts. This will allow a limited number of homogeneous vehicles to explore uses like search and rescue, agriculture applications, humanitarian, or science missions. Future TCLs planned through FY 2019 will add additional capabilities.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

### Thrust 1: Safe, Efficient Growth in Global Operations

The development of ATD-1 flight-deck interval management technologies will culminate in flight test demonstrations planned for early FY 2017. NASA will install and evaluate prototype flight hardware and software based on an algorithm for Airborne Spacing for Terminal Arrival Routes. Upon successful integration of the systems in the demonstration, final analysis, documentation, and technology transfer to the FAA will occur late FY 2017.

NASA will conduct an ATD-2 Departure Metering demonstration at Charlotte Douglas International Airport, the test site for this initial simulation of a NextGen departure metering capability. This demonstration supports the FAA's joint government/industry initiative aimed at improving air traffic flow management through increased information exchange among airline and airport stakeholders.

### Thrust 5: Real-time, System-wide Safety Assurance

In late FY 2017, the Beta build of the SMART-NAS Test Bed will deliver capabilities to (1) evaluate emergent air traffic behavior due to novel air traffic control concepts and (2) provide the FAA and airspace users the ability to evaluate mature concepts/technologies. These capabilities will enable the community to perform high-fidelity training using on-demand HITL simulation capabilities with realistic traffic and weather conditions. These capabilities do not exist in modeling and testing environments available today.

### Thrust 6: Assured Autonomy for Aviation Transformation

NASA will continue to develop and mature UTM technology by way of TCL 2, which will incorporate weather/wind integration, trajectory routing, object avoidance, and congestion management in the first quarter of FY 2017. These additional capabilities will support more complex and beneficial operations in low altitude airspace. TCL 2 will leverage TCL1 results and focus on beyond-visual line-of-sight operations in sparsely populated areas. Researchers will test technologies that allow dynamic adjustments to user-requested flight plans based on availability of airspace and contingency management.

# Program Elements

## AIRSPACE TECHNOLOGY DEMONSTRATIONS (ATD)

The Airspace Technology Demonstrations project is comprised of a suite of critical technology development and demonstration activities geared toward delivery of near-term benefits to air transportation system stakeholders. These benefits strongly align with the objectives for the Clean Air Transportation initiative. ATD supports the ARMD safe efficient growth in global operations strategic thrust by five sub-projects with each focused on a technical challenge.

- ATD-1 (Interval Management - Terminal Area Precision Scheduling and Spacing) will directly address terminal area congestion, and evaluate the benefits of advanced flight arrival management technologies across a range of aircraft equipment levels during moderate to high levels of traffic demand. When integrated, the ATD-1 technologies will allow the pilots to achieve precise spacing separation between aircraft, and the controllers to manage the variability between flights and respond to disturbances to the schedule. This integrated set of capabilities will enable increased fuel efficiency while maintaining runway throughput to high-density airports.
- The IADS, or ATD-2, activity will develop and adjust precision schedules for gates, runways, arrival, and departure fixes while ensuring efficient individual aircraft routes. IADS will reduce unnecessary buffers imposed by the human workload associated with the tasks of simultaneously coordinating and scheduling of arrivals, departures, and runway and surface operations.
- The Domestic Applied Traffic Flow Management activity aims to reduce weather-induced delays through sharing of information to better manage aircraft, traffic flow, and airspace and schedule limitations. Benefits to the community are smarter alterations of routes to avoid hazardous weather, modern data connectivity, and real-world testing for big improvements in delay reductions and fuel and time savings.
- The Oceanic Applied Traffic Flow Management activity will increase capacity and operational efficiency in oceanic airspace by leveraging satellite navigation broadcasting technology to reduce minimum separation distance between aircraft. This sub-project will develop procedures and technologies that offer optimal use of wind in flight routes with advantages of reduced fuel, emissions, and travel delays.
- The goal of the Technologies for Airplane State Awareness activity is to identify risks and provide knowledge needed to avoid, detect, mitigate, and recover from hazardous flight conditions that have led to fatal aviation accidents worldwide. Partnering with other government agencies and the Commercial Aviation Safety Team, NASA will demonstrate new capabilities

that enable pilots to better understand and respond safely to complex situations, and to improve operator effectiveness in aviation safety.

## SHADOW MODE ASSESSMENT USING REALISTIC TECHNOLOGIES FOR THE NATIONAL AIRSPACE SYSTEM (SMART-NAS)

The SMART-NAS Project will develop and integrate concepts, technologies, and architectures at the system level of the NAS to deliver safe, system-wide operations for gate-to-gate NextGen performance. To accelerate the transformation of the entire NAS, proposed operational capabilities must be integrated and demonstrated to gain confidence in the performance of the entire system. A shadow-mode NAS will be developed that takes actual operational input from the NAS (weather, flight plans, airports' arrival rates, system constraints, etc.), and simulates the entire system (or parts of it) using proposed alternative architectures, concepts, and technologies to demonstrate performance and validate safe, seamless operations. This research primarily aligns with the real-time system-wide safety assurance strategic thrust area as it will examine, in real-time, robustness, reliability, and stability of concepts, algorithms, and technologies as compared with current NAS operations. To achieve these capabilities, SMART-NAS will employ advanced prognostics, data mining, and data analytics for enhanced decision-making and system assessments. The SMART-NAS Project will reduce the time to test concepts, technologies, and their interactions, interoperability, and integration. It will be capable of real/live, virtual, constructive, and hybrid mode operations to simultaneously operate in real and virtual traffic. SMART-NAS will enable assessments to demonstrate practical and achievable benefits that could support a variety of decisions to modernize the current NAS.

## SAFE AUTONOMOUS SYSTEMS OPERATIONS (SASO)

In support of ARMD's strategic thrust toward assured autonomy for aviation transformation, the SASO Project will conduct research and development activities to ensure that the future airspace management system will accommodate far greater levels of system complexity. The needs are characterized by greater diversity of aircraft performance, user business models, and airspace requirements. The system must also ensure scalability of operations, and affordability for service providers and users. Combinations of increasingly autonomous technologies using automation (which follows scripted operational procedures), autonomy (which follows logic to make operational decisions), and automaticity (which supports self-management of large-scale systems) will be considered to meet the next century of airspace operational needs. The fundamental objective of the SASO Project is to identify justifiable combinations of automation, autonomy, and automaticity to safely meet these future needs. The project has two sub-projects with technical challenges:

- Development of a UTM system to safely enable low-altitude UAS operations;
- Development of technologies, roles and responsibilities, and procedures to demonstrate technical feasibility of reduced crew operations (RCO);

SASO is also exploring fundamental and cross-cutting research and development activities:

- Development of technologies, roles and responsibilities, and procedures to demonstrate feasibility of autonomous aircraft operations in terminal areas;
- Enabling autonomous traffic flow management that allow more robust decision making in the presence of weather forecast uncertainties, developing alternative plans and dynamically

changing the plans as forecasts change, and using learning algorithms/automation based on historical analysis of performance.

## Program Schedule

| Date | Significant Event |
|---|---|
| Mar 2015 | Conducted full-scale integrated ATD-1 simulations on operational platforms at the FAA William J. Hughes Technical Center. Conducted analysis of Surface Collaborative Decision-Making Procedure. |
| Sep 2015 | Co-hosted the UTM Convention with over 1,200 participants with panel discussions on policy issues, emerging markets and operations, and strategies.<br>UTM TCL 1 demonstration of the initial system prototype with multiple partners. |
| Jun 2016 | RCO TCL 1 demonstration of initial RCO operating in nominal scenarios. |
| Sep 2016 | Conduct fast-time HITL simulations and analysis to establish feasibility of IADS technical approaches. |
| Dec 2016 | ATD-1 flight test demonstration of prototype flight deck interval management avionics<br>UTM TCL 2 – incorporate TCL 1 with focus on increased density and contingency management. |
| Jun 2017 | Field test to demonstrate surface departure metering components of metroplex departure metering with airline partner at Charlotte Douglas International Airport.<br>RCO TCL 2 demonstration of initial RCO operating in off-nominal scenarios. |
| Sep 2017 | Final ATD-1 flight deck interval management avionics research technology transfer to the FAA and technology challenge closeout.<br>Initial beta build of a safety analysis and assurance toolkit, which include data mining and analysis, automated prognostics, and safety risk modeling capabilities in the SMART NAS Testbed. |
| Dec 2017 | Validate technologies to enhance flight crew attitude and energy state awareness; develop tools and methods for collecting and analyzing real-time flight crew performance data. |
| Mar 2018 | UTM TCL 3 – incorporate TCL 2 and manage separation by vehicle and/or ground-based capabilities under higher densities. |
| Sep 2018 | Release of SMART NAS Testbed Production Build 1 to the aviation community.<br>RCO TCL 3 demonstration of integrated multi-facility simulation of RCO capabilities. |

# AIRSPACE OPERATIONS AND SAFETY PROGRAM

| | |
|---|---|
| Mar 2019 | Incorporate Weather Integrated Decision-Making design build with NASA partners. |
| Jun 2019 | UTM TCL 4 to incorporate TCL 3 and manage large-scale contingencies. |
| Sep 2019 | Release of SMART NAS Testbed Production Build 2 to the aviation community. |
| Jun 2020 | Full-system demonstration of IADS metroplex departure scheduling concept. |

## Program Management & Commitments

| Program Element | Provider |
|---|---|
| Airspace Technology Demonstrations | Provider: Ames Research Center (ARC), Langley Research Center (LaRC), GRC<br>Lead Center: ARC<br>Performing Center(s): ARC, LaRC, GRC<br>Cost Share Partner(s): FAA, Honeywell, General Electric, Boeing, Raytheon, Rockwell Collins, Goodrich, Cessna Aircraft Co., American Airlines, United Airlines, EasyJet, Southwest Airlines, Commercial Aviation Safety Team (CAST), DoD, French Aerospace Lab (ONERA) |
| SMART-NAS | Provider: ARC, LaRC, GRC<br>Lead Center: ARC<br>Performing Center(s): ARC, LaRC, GRC<br>Cost Share Partner(s): FAA, General Electric, American Airlines, United Airlines, Rockwell Collins , Boeing, DoD, EasyJet, Honeywell, ONERA, Southwest Airlines |
| SASO | Provider: ARC, LaRC, Armstrong Flight Research Center (AFRC), GRC<br>Lead Center: ARC<br>Performing Center(s): ARC, LaRC, AFRC, GRC<br>Cost Share Partner(s): FAA, Boeing, General Electric, American Airlines, United Airlines, Rockwell Collins, DoD, Honeywell, ONERA |

## Acquisition Strategy

The AOSP spans research and technology from foundational research to integrated system capabilities. This broad spectrum necessitates the use of a wide array of acquisition tools relevant to the appropriate work awarded externally through full and open competition. Teaming among large companies, small businesses, and universities is highly encouraged for all procurement actions.

# AIRSPACE OPERATIONS AND SAFETY PROGRAM

## MAJOR CONTRACTS/AWARDS

NASA's Aeronautics programs award multiple smaller contracts, which are generally less than $5 million. They are widely distributed across academia and industry. In FY 2015, AOSP awarded the following totaling over $5 million:

| Element | Vendor | Location (of work performance) |
|---|---|---|
| System-level demonstrations of integrated NASA arrival management technologies | Boeing | Moses Lake, WA<br>Seattle, WA<br>Hampton, VA |

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Formulation SMART-NAS and SASO projects | ARMD Senior Management and Expert Review | Nov 2015 | The Formulation Review evaluates the projects' goals and stated deliverables to ensure proper formulation and alignment with Agency and ARMD strategic objectives. The review assesses the competence of technical challenge pre-formulation efforts. | The SMART-NAS and SASO Projects were approved to begin implementation based on demonstration of sufficient maturity of technical challenges | Jan 2016 |
| Performance (Annual) | Expert Review | Oct 2015 | The 12-month review is a formal independent peer review. Experts from other government agencies report on their assessment of technical and programmatic risk and/or program weaknesses. | Determined that the projects made satisfactory progress in meeting technical challenges and met all annual performance indicators. | Oct 2016 |

# ADVANCED AIR VEHICLES PROGRAM

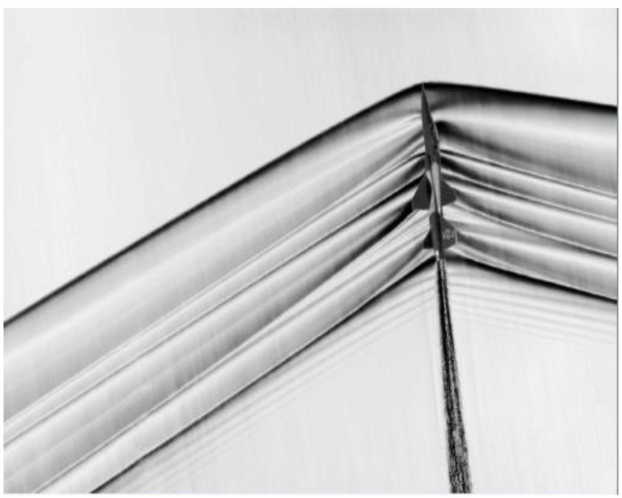
## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **240.6** | **--** | **298.6** | **277.4** | **308.8** | **311.6** | **312.6** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*



**NASA used a 21st century version of schlieren imagery, invented by a German physicist in 1864, to visualize supersonic flow phenomena with full-scale aircraft in flight.**

AAVP develops knowledge, technologies, tools, and innovative concepts to enable safe, new aircraft that will fly faster, cleaner, quieter, and use fuel far more efficiently. As the country continues to experience growth in both domestic and international air transportation, the AAVP helps to protect and preserve the environment. NASA research is inherent in all major modern U.S. aircraft, and the type of research performed by AAVP will prime the technology pipeline, enabling continued U.S. leadership, competitiveness, and jobs in the future. Technologies and design capabilities developed for these advanced vehicles will integrate multiple, simultaneous vehicle performance considerations including fuel burn, noise, emissions, and intrinsic safety. Across the program, NASA will continue to engage partners from industry, academia, and other government agencies to maintain a sufficiently broad perspective on technology solutions to these challenges; to pursue mutually beneficial collaborations; and to leverage opportunities for effective technology transition. AAVP directly supports three of the ARMD Strategic Thrusts (Thrust 2: Innovation in Commercial Supersonic Aircraft, Thrust 3: Ultra-efficient Commercial Vehicles, and Thrust 4: Transition to Low-Carbon Propulsion.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| Mandatory Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **21st Century Clean Transportation Plan** | **--** | **--** | **30.0** | **41.0** | **79.0** | **80.0** | **65.0** |

# ADVANCED AIR VEHICLES PROGRAM

In FY 2017, AAVP is supported in part by funding under a multiagency 21st Century Clean Transportation Plan. This initiative extends beyond the five-year period covered in this document. Full funding for the initiative in AAVP is $0.6 billion over 10 years.

Continuing to build off of the major success of the ERA project, NASA will increase high technology readiness level (TRL) ground testing in cost-sharing partnerships with industry to mature and transition advanced technologies to increase the efficiency and reduce the environmental impact of commercial aircraft. AAVP will begin a series of high fidelity experiments to support, along with NAH design studies, achievement of a PDR in FY 2018 for an HWB configuration as well as for additional purpose-built demonstrator aircraft to follow shortly after.

In FY 2017, NASA will establish the HT Project. NASA will balance investments that support and leverage the work of the DoD with investments in fundamental hypersonics research.

## ACHIEVEMENTS IN FY 2015

### Thrust 2: Innovation in Commercial Supersonic Aircraft

NASA’s progress in low-noise commercial supersonic flight continued to advance the nation’s readiness for experimental flight demonstration of this capability. NASA completed experimental and analytical studies of jet engine exhaust and studies of the interactions of the exhaust with shock waves generated in supersonic flight. Specifically, NASA performed assessments of exhaust effects utilizing CFD analysis with comparison to experimental test data from the NASA GRC 1x1-Foot Supersonic Wind Tunnel. Understanding these jet engine exhaust effects were the final step needed to develop a first-of its kind set of low sonic boom aircraft design tools that NASA made available to industry. These unique tools enable aircraft design engineers to rapidly and directly design for low sonic boom noise - providing industry the ability to confidently design new supersonic commercial aircraft once a low boom noise standard is achieved through the regulatory process.

### Thrust 3: Ultra-efficient Commercial Vehicles

The AAV Program conducts research across a wide spectrum of vehicle classes that ultimately contribute to Thrust 3. To help show the promise of new configurations NASA completed testing of a hybrid wing concept in the National Transonic Facility that both explored concepts with the potential to enable significant efficiency improvements and also validated improvements made to the facility. These facility benefits will have a significant impact on future NASA and industry testing and will help with risk reduction needed for other configurations. In addition, NASA completed an initial system level assessment of an advanced small jet engine core concept. This very small engine core concept could improve fuel savings by ~30 percent compared to today’s technology and may also enable new configurations. This propulsion research is an important step for future aircraft and engine systems that may result from NASA’s planned X-Planes because new engines will be needed to fully realize the benefits of the aircraft shapes.

Improved structures and materials will benefit most new air vehicles. NASA completed the establishment of a public-private partnership entitled the Advanced Composite Consortium (ACC). The ACC facilitates the collaboration between NASA and cost-sharing industry partners to make it possible to implement these new materials faster in new designs. In order to help guide and inform this research NASA created a Development to Certification Timeline (DCT) tool for composite structures. This tool helps to (1) analyze the time associated with phases of product development, (2) estimate reductions in time associated with project technologies, and (3) define performance measures for those technologies. The DCT provides a framework for measuring system-level impacts of multiple technology advances, and forms the foundation for project operation and assessment of progress toward the project goal.

Since there are a number of environmental challenges (especially noise) related to vertical flight, NASA completed acoustic flight testing of two helicopter configurations at three flight altitude conditions confirming the differences in noise produced at the different altitudes. The data from the three altitudes generated an altitude correction for rotorcraft noise models that was not previously included in acoustic prediction tools. The data has increased the accuracy of rotorcraft noise prediction tools, improving the ability to design quieter rotorcraft configurations. NASA also completed the Transport Rotorcraft Airframe Crash Testbed research. This research evaluated the survivability of occupants in different seats, locations, and restraint systems during a controlled impact. NASA will access the crashworthiness improvements of the helicopter structure by the addition of composite, energy-absorbing subfloors using three different types of subfloor composite construction. The data improved safety and survivability for all types of vehicles with conventional and composite construction.

NASA conducted a series of tests in the GRC Icing Research Tunnel (IRT) to validate a methodology to allow ice accretion on commercial transport aircraft using a full-scale, leading edge truncated wing. This data will enable the testing of transport aircraft size wing models in the IRT without increasing the size of the current test section. Such testing capability is valuable to ensuring that advanced ultra-efficient aircraft designs will also be safe in icing conditions.

### Thrust 4: Transition to Low-Carbon Propulsion

NASA completed analysis, documentation, and dissemination of test results from a flight campaign to characterize the gaseous and particulate cruise emissions of biofuel-blended jet fuels, and effects of fuel sulfur during flight at cruise conditions. This internationally recognized data set (at https://aero-fp.larc.nasa.gov/) enables the atmospheric science community to continue to improve emissions modeling and guides the development of international standards for aircraft emissions when drop-in alternative fuels are used.

### Cross-Cutting Capabilities

NASA entered the first phase in Test Section Optical Improvements in the ARC 11x11-Foot and 9x7-Foot Wind Tunnels laying the foundation for major advances in optical access, data gathering, and off-body measurements. Improvements in optical measurements using infrared thermography, pressure sensitive paint, advanced photogrammetry, and Schlieren techniques enabled major advancements in measurement accuracy and flow visualization. These major improvements in wind tunnel data are critical for comparison to, and validation of, the next generation computational simulations. The 11x11-Foot and the 9x7-Foot Wind Tunnels have been at the forefront of testing and optical data gathering with these techniques and will continue to be for the foreseeable future. Test capability improvements such as these are vital for future risk reduction tests of new configurations before proceeding to flight because they greatly improve our ability to observe and understand complex aerodynamics and are also critical for validating computational models too.

# ADVANCED AIR VEHICLES PROGRAM

## WORK IN PROGRESS IN FY 2016

### Thrust 2: Innovation in Commercial Supersonic Aircraft

NASA will achieve a major milestone in enabling development of low noise commercial supersonic aircraft by completing the Low Noise Propulsion for Low-Boom Aircraft technical challenge. This technical challenge addresses the development of computational design tools and innovative concepts for integrated low-noise supersonic propulsion systems and demonstrates these concepts through ground testing. Although overcoming the barrier of sonic boom noise is a primary focus in this Thrust, this research effort recognizes that future commercial supersonic aircraft will have to meet the same stringent airport noise regulations that govern the subsonic fleet. The planned activity addresses the challenge of designing low sonic boom noise aircraft that also meet the current airport noise requirement and also anticipates an increase in the stringency of the noise requirement in the future.

### Thrust 3: Ultra-efficient Commercial Vehicles

NASA will engage in risk reduction testing of key concepts and technologies that may be incorporated into future flight demonstrators. One example of such testing includes the advancement and validation of the high-speed performance and aerodynamic design of a TBW aircraft conceptual design as a viable technology to reduce fuel use and emissions. To design the detailed novel aerodynamic shape of the configuration, NASA will use high fidelity, CFD-based aerodynamic methods currently being advanced. One unique challenge for the TBW concept is the design of a low-drag truss structure and its integration with the wing and fuselage. To validate the design and contribute to an update of the integrated system assessment of this TBW concept, NASA will test a high-fidelity aerodynamic wind tunnel model in the 11x11-Foot Transonic Wind Tunnel at ARC. Other risk reduction tests will be initiated and conducted in order to facilitate the new concepts being considered for NAH.

NASA will select progressive damage analysis (PDA) technologies for further development in the second phase of the Advanced Composites Project. By comparing blind predictions with experimental results, NASA will complete characterization of PDA methods, non-destructive inspection technology, and manufacturing process models for composites (current capability and technology gaps). When complete, these PDA models will provide damage progression methods that more accurately represent the failure mechanics for the composite structural component and applied loading. To validate the performance of previously selected PDA models and to identify the required data to down-select the best performing models for future development and evaluation during the second phase of the project.

In partnership with other Government agencies and industry, NASA will demonstrate a new type of engine power turbine that will advance the efficiency of propulsion systems for future vertical lift vehicles. The Variable-Speed Power Turbine (VSPT) component tests will demonstrate the ability to operate the power turbine efficiently over a wide operating speed range of the engine. The VSPT concept will result in engines and vehicles with higher performance and greater fuel efficiency.

### Thrust 4: Transition to Low-Carbon Propulsion

NASA will develop a detailed conceptual design of a hybrid gas-electric propulsion system for a transport class aircraft and assess its overall vehicle-level benefits in terms of noise, emissions, and energy consumption. Work will also continue in partnership with several universities to design and develop motors capable of high power while reducing the overall weight of the machines. These improved high efficiency machines will allow earlier adoption of electric technologies in aircraft.

### Cross-Cutting Capabilities

NASA will complete studies to determine the most promising SLD icing (i.e. freezing drizzle and rain) experimental simulation methods. The ability to provide an SLD freezing drizzle/rain environment in a ground test facility will allow for the efficient and effective testing of aircraft components, computer simulation validations and SLD freezing drizzle/rain protection systems. The ability to provide an SLD freezing drizzle/rain environment in a ground test facility does not currently exist, and future air vehicles will need to operate safely under SLD-like conditions.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

### Thrust 2: Innovation in Commercial Supersonic Aircraft

In support of the future LBFD flight experiments, NASA will complete development of an initial set of models for the prediction of the community response to noise created by the overflight of future supersonic commercial aircraft. Based on simulations conducted in NASA's Interior Effects Laboratory, the first of these models will be capable of predicting the response of a person who hears supersonic overflight noise while indoors. This model evaluates the level of noise required to prevent annoyance due to supersonic overflight. The second of these models will be able to predict the indoor noise created by supersonic overflight in a wide variety of homes with different room arrangements and construction techniques. With the combination of these models, NASA will begin analytical studies of community response to the overflight of future low noise supersonic commercial aircraft, enabling NASA to design the LBFD community overflight experiments.

### Thrust 3: Ultra-efficient Commercial Vehicles

NASA will test a revolutionary engine inlet-fan configuration at the GRC, through an NRA with UTRC. NASA will begin the evaluation of performance of this very promising, unique engine inlet-fan design for its vehicle-level fuel burn benefits at flight conditions that are typical of a modern transport aircraft. With this testing, NASA will complete a technical challenge related to understanding the interaction effects between engines and airframes for some specific configurations. This is also important for understanding an important design consideration for a potential subsonic demonstrator. In addition to this test, NASA will conduct other key ground tests to further understand the potential of new configurations and reduce risk for subsonic demonstrators.

NASA will initiate Phase II of the Advanced Composites Project. As in Phase I, NASA will work very closely with industry partners and the FAA and will focus on honing the results of Phase I so that each of the Technical Challenges can be completed and have optimum benefit to the community. A key area will be the validation of the tools and techniques developed in the first phase on relevant structures. As with other similar projects before (ERA and UAS in the NAS), NASA will review the Phase I progress and Phase II plans with an independent review panel of experts.

In order to help improve the efficiency and performance of new vertical flight concepts NASA will demonstrate a two-speed transmission drive system that enables operation over a 50 percent range in main rotor revolutions per minute (RPM). This experimental drive system is able to efficiently transmit high torque. To offset potential two-speed transmission weight increase in the final application, complementary, advanced technologies to reduce transmission component weight will be advanced and demonstrated. With this key transmission test as well as the remaining work associated with the VSPT,

# ADVANCED AIR VEHICLES PROGRAM

NASA will complete two technical challenges that provide viable, enabling options for varying the speed of large rotors, which has been long sought after as an approach to make vertical lift systems faster and more efficient. It is likely that one or both of these concepts will be utilized in the next generations of both civil and military vertical lift vehicles.

### Thrust 4: Transition to Low-Carbon Propulsion

NASA will conclude preparations for the testing of a superconducting motor. This motor test represents a major advancement in a key technology needed to realize practical larger-scale hybrid electric propulsion systems in the future. Further, in partnership with industry, NASA will advance a 1MW non-superconducting inverter to a maturity of TRL4. This advancement complements the superconducting motor and adds to the technology options available to hybrid electric propulsion system designers as they identify and develop larger ground and flight demonstration opportunities.

### Cross-Cutting Capabilities

NASA will complete design and installation of new acoustical treatment in the GRC 9x15-Foot Low Speed Wind Tunnel. This improvement will further reduce the facility background noise to levels that enable testing of next-generation low noise propulsion system concepts. Additionally, NASA will incorporate a new funding model for operational costs for NASA ground test facilities. This funding model enhances the value of ground testing for generating the data necessary to both better understand the performance of new technologies and help validate key computational models. NASA will benefit from the additional facility utilization for program/project risk reduction and Center innovation initiatives. In particular, it is expected that this new model will facilitate the risk reduction testing needed to support the NAH initiatives. It will provide consistent usage, stewardship of ground test capabilities, and increased level of actual strategic investments to sustain and improve the portfolio of covered capabilities.

### Hypersonic Capabilities

NASA will continue to coordinate closely with the DoD to leverage flight test data to support NASA’s research while simultaneously reducing risk and enhancing these efforts. NASA will also initiate a new focus to reduce the uncertainty in computational tools, ground testing, and flight experimentation. This key barrier to both reducing risk and enabling more effective technology risks in the near term allows for a better understanding of the true potential for the technology for future applications that are of interest to NASA. Finally, NASA will conduct ground test experiments to help show the feasibility for future systems that can use a turbine engine at slow speeds and transition to a scramjet for high-speed operations. This would greatly increase the flexibility and utility of high-speed vehicles.

# Program Elements

## ADVANCED AIR TRANSPORT TECHNOLOGY

NASA’s vision for advanced fixed wing subsonic transport aircraft is to enable revolutionary advances in energy efficiency and environmental compatibility of future generations of aircraft. These technological solutions are critical to reduce the impact of aviation on the environment even as this industry and the corresponding global transportation continue to grow. Research will explore and advance knowledge, technologies, and concepts to enable major steps in energy efficiency and environmental compatibility resulting in less fuel burned, less direct impact on the atmosphere, and less noise around airports. This project will identify potential new safety considerations associated with these advanced technologies and concepts. This critical research helps the sustained growth of commercial aviation that is so vital to the U.S. economy and our quality of life. The knowledge gained from this research, in the form of experiments, data, system studies and analyses, is critical for conceiving and designing more efficient, quieter, and greener aircraft. Advanced air transport research directly supports ARMD Strategic Thrusts 3

# ADVANCED AIR VEHICLES PROGRAM

and 4 and will focus on developing advanced technologies and tools for future generations of commercial transports - including key risk reduction activities for potential subsonic demonstrators in the NAH initiative as well as the core propulsion research needed to develop new engines that will ultimately power the new vehicles stemming from NASA’s focus on 21st Century Clean Transportation.

## REVOLUTIONARY VERTICAL LIFT TECHNOLOGY

The NASA Revolutionary Vertical Lift Technology (RVLT) project develops and validates tools, technologies, and concepts to overcome key barriers to the expanded use of vertical lift configurations in the Nation’s airspace. The unique ability of vertical lift vehicles to hover has great potential in the civil market for human and cargo transportation, delivery systems, inspection and surveillance missions, oil and gas exploration, disaster relief and many more critical operations. RVLT research advances technologies that will increase speed, range, payload, and safety as well as decrease noise, weight, and fuel burn. To accomplish this research, NASA uses advanced computer-based multi-fidelity prediction methods, unique NASA facilities, and state-of-the art experimental techniques. RVLT considers current and future vertical lift vehicles of all classes and sizes, ranging from very small configurations to configurations that are viable commercial transports in the NAS. For example, the Project is currently working with TACP to explore ideas that may combine autonomy and hybrid/ full electric systems with a vertical lift capability to enable a variety of new civil missions. The RVLT Project primarily supports ARMD Strategic Thrust 3, but in the future will likely incorporate more electric and autonomy technologies that will also support Strategic Thrusts 4 and 6.

## COMMERCIAL SUPERSONIC TECHNOLOGY

Supersonic vehicle research includes tools, technologies, and knowledge that will help eliminate today’s technical barriers to practical, commercial supersonic flight. These barriers include sonic boom; supersonic aircraft fuel efficiency; airport community noise; high altitude emissions; vehicle aeroservoelastic design; supersonic operations and the ability to design future vehicles in an integrated, multidisciplinary manner. Research conducted will establish the necessary approaches and techniques for objectively measuring the levels of sonic boom acceptable to communities living in the vicinity of future commercial supersonic flight paths. These approaches, techniques, and resulting data will inform both national and international regulatory organizations that set the standards for commercial entities and vehicles to achieve. The research also lays the groundwork for overcoming other challenges facing commercial supersonic flight including energy efficiency, reduced pollutants emitted into the atmosphere, and acceptable engine noise levels in the airport area. The Commercial Supersonic Technology Project directly supports ARMD Strategic Thrust 2 and will conduct the research leveraging the purpose-built LBFD in conducting the community response mission.

## ADVANCED COMPOSITES

NASA is addressing new test protocols and methods to reduce the development and certification timeline for composite materials and structures. It is inevitable that composite structures will see increased application due to the pressure to develop more efficient, sustainable vehicles. Testing is the primary basis of the present approach for the development and certification of composites. It is time-consuming and expensive but does provide rigorously validated results. NASA will focus on the development and use of high fidelity and rigorous computational methods, improved test protocols, and standardized

# ADVANCED AIR VEHICLES PROGRAM

inspection techniques to shorten the timeline to bring innovative composite materials and structures to market. NASA will engage key players from Government (FAA and DoD), industry, and academia to mature and verify the methodology, to ensure effective transition to industry, and to assure safety for certification authorities, such as the FAA. The goal of the project is to reduce the estimated 5 to 9 year timeline for composite structures development and certification by 30 percent. The Advanced Composites Project directly supports ARMD Strategic Thrust 3 because it will facilitate the design of new advanced vehicles that are highly efficient. In addition, there is applicability to Thrust 2 because future supersonic aircraft may likely use composites too.

## AERONAUTICS EVALUATION AND TEST CAPABILITIES

The ground test capabilities (facilities, systems, workforce, and tools) necessary to achieve the future air vehicles and operations described above require efficient and effective investment, use, and management. Efforts in this area preserve and enhance those specific ground test capabilities that are necessary to achieve the missions. Among these assets are subsonic, transonic, supersonic, and hypersonic wind tunnels and propulsion test facilities at ARC, GRC, and LaRC. These NASA-unique test facilities and capabilities may also serve the needs of the nation. This integrated approach to asset planning, use, and management will consider the complementary computational tools, software, and related systems to effectively acquire and process research data. An additional benefit is to offer the research customer high-quality data that accurately reflects the simulated test environment and the interactions of test articles in those test environments in conjunction with the ground experimentation capabilities. Furthermore, it includes the NASA expertise that helps ensure safe and successful use of the assets and high quality of the research outcomes. NASA will also conduct research on key hypersonic technologies that support this national capability. This work concentrates in areas such as development of new computational tools and key technologies that open the possibility for greater use of air-breathing hypersonic systems in the future. The project is cross cutting and supports ARMD Strategic Thrusts 2, 3, and 4 as well as other Agency efforts and those of key industry partners.

## HYPERSONICS TECHNOLOGY PROJECT

The development of new hypersonic capabilities is important for the country. In the near-term application of hypersonics is likely to be on enhanced defense systems, but this could eventually expand to include improved access to space capabilities that would directly benefit NASA. NASA maintains unique specialized facilities and experts who will focus on key fundamental research areas that explore key challenges in high-speed flight. This project will coordinate closely with partners in the DoD so that NASA can leverage their investment in flight activities to develop and validate advanced physics-based models and at the same time, the DoD can benefit from NASA expertise, analyses, testing capabilities and computational models. Focus areas for the project include high-speed propulsion systems, re-usable vehicle technologies, high-temperature materials, and systems analysis.

## Program Schedule

| Date | Significant Event |
|---|---|
| Nov 2015 | Complete the analysis to quantify the drag reduction benefit of boundary layer ingestion for a representative aircraft configuration. |
| Sep 2016 | Complete component testing of a variable speed power turbine with potential to greatly improve turboshaft engine efficiency over a wide operating range. |
| Sep 2016 | Complete an integrated analysis of advanced, candidate technologies contributing to a 1.5-2 times increase in the aspect ratio of a lightweight wing with safe flight controls and structures. |
| Dec 2016 | Complete the second phase of test section improvements of the optical access, physical access, and the related support infrastructures designed in previous phases, which will enable advanced optical test techniques such as Pressure Sensitive Paint, Infrared Thermography, High Speed Schlieren, Model Deformation, and Particle Imaging Velocimetry to be routinely used in ARC Unitary Plan Wind Tunnel testing. |
| Sep 2017 | Define the natural ice-crystal cloud environment in terms of altitude, temperature, ice water content, particle size, and morphology to guide the engine ice crystal ingestion testing in the Propulsion Systems Laboratory at NASA GRC. |
| Sep 2017 | Complete the replacement of the facility control system and steady state data acquisition systems at both the GRC 8X6-Foot Supersonic Wind Tunnel and 9X15-Foot Low Speed Wind Tunnel to enable world-class steady state data capabilities including higher reliability, channel count, processing rates, analyses, improved plotting, a higher reliability, and more versatile control system. |
| Sep 2017 | Demonstrate a two-speed drive system for vertical lift applications that can operate with a 50% shaft speed change and efficiently transfer high torque with no weight penalty. |
| Sep 2017 | Complete functional checkout and assessment of the Tiltrotor Test Rig (TTR) to demonstrate a new test capability for high-speed vertical lift configurations. |
| Sep 2018 | Complete fan model testing with a Single-Degree of Freedom (SDOF) and Multiple-Degree of Freedom (MDOF) in the NASA GRC 9x15 Foot Low Speed Wind Tunnel to provide significant improvement in the noise reduction capability of liners. |
| Sep 2018 | Complete Tests of N+3 low-emission, fuel-flexible combustor concept |

# ADVANCED AIR VEHICLES PROGRAM

## Program Management & Commitments

| Program Element | Provider |
|---|---|
| Advanced Air Transport Technology | Provider: ARC, AFRC, GRC, LaRC<br>Lead Center: GRC<br>Performing Center(s): ARC, AFRC, GRC, LaRC<br>Cost Share Partner(s): U.S. Air Force, Boeing, Pratt & Whitney, Northrop Grumman, General Electric Aviation, Aurora, United Technologies Corporation, Rolls Royce/Liberty Works, Honeywell, FAA, Lockheed Martin, U.S. Navy, U.S. small business and universities |
| Revolutionary Vertical Lift Technology | Provider: ARC, GRC, LaRC<br>Lead Center: LaRC<br>Performing Center(s): ARC, GRC, LaRC<br>Cost Share Partner(s): UTRC, U.S. Army,<br>GE, Pratt and Whitney, Joby Aviation DLR, NLR, U.S. Navy, U.S. small businesses and universities |
| Commercial Supersonic Technology | Provider: ARC, GRC, LaRC, AFRC<br>Lead Center: LaRC<br>Performing Center(s): ARC, GRC, LaRC, AFRC<br>Cost Share Partner(s): Boeing, General Electric Aviation, Gulfstream Aerospace, U.S. Air Force, FAA, JAXA, Honeywell, Rockwell Collins, KTH, Sweden, Lockheed Martin, Aerion Corporation, U.S. Navy, U.S. small businesses and universities |
| Advanced Composites | Provider: ARC, GRC, LaRC<br>Lead Center: LaRC<br>Performing Center(s): ARC, GRC, LaRC<br>Cost Share Partner(s): Boeing, General Electric Aviation, Lockheed Martin, , United Technologies Corporation, FAA, DOD |
| Aeronautics Evaluation and Test Capabilities | Provider: ARC, GRC, LaRC, AFRC<br>Lead Center: N/A<br>Performing Center(s): ARC, GRC, LaRC<br>Cost Share Partner(s): DoD, FAA, European High Altitude Ice Crystal (HAIC) Consortium, Boeing, SEA In.c |
| Hypersonics Technology | Provider: GRC, LaRC<br>Lead Center: TBD<br>Performing Center(s): LaRC and GRC<br>Cost Share Partners: TBD |

# Acquisition Strategy

Research and technology spans from foundational research to integrated system capabilities. This broad spectrum necessitates the use of a wide array of acquisition tools relevant to the appropriate work awarded externally through full and open competition. Teaming among large companies, small businesses, and universities is highly encouraged for all procurement actions.

## MAJOR CONTRACTS/AWARDS

NASA's Aeronautics programs award multiple smaller contracts, which are generally less than $5 million. They are widely distributed across academia and industry.

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | Expert Review | Nov 2015 | The 12-month review is a formal independent peer review. Experts from other Government agencies report on their assessment of technical and programmatic risk and/or program weaknesses. | The Panel provided favorable reviews to the projects. The Panel also gave constructive comments and recommendations. | Nov 2016 |

# INTEGRATED AVIATION SYSTEMS PROGRAM

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | 150.0 | -- | 210.0 | 255.4 | 381.4 | 493.0 | 556.7 |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

**In this photo taken from a chase plane, the Boeing ecoDemonstrator 757 flight test airplane --with NASA's Active Flow Control technology installed on the tail -- makes a final approach to King County Boeing Field in Seattle, Washington.**

One issue that NASA faces is bridging the gap between the maturity level of technologies developed through fundamental research and the maturity requirement of infusion into future air vehicles and operational systems.

The goal of IASP is to demonstrate integrated concepts and technologies at a maturity level sufficient to reduce risk of implementation in the aviation community. IASP focuses on the rigorous execution of highly complex flight tests and related experiments. These flight tests support all phases of ARMD research, not just the culmination of research activities. For technologies at low TRLs, IASP flight research accelerates the development and/or determines the feasibility of those technologies. For more mature technologies, flight research will reduce risks and accelerate transition of those technologies to industry.

IASP addresses the national challenge of routine access of UASes into the NAS for civil use. Historically, UAS have supported military and security operations overseas, with training occurring primarily in the United States. However, significant interest is growing in civil uses, including commercial photography, aerial mapping, crop monitoring, advertising, communications, and broadcasting. The FAA is developing new policies, procedures, and approval processes to address the increasing civil market and the desire of civilian operation of UAS on a routine basis. The need for developing and implementing new standards, procedures, and guidance to govern civil UAS operations in the NAS in a timely manner has become more important than ever. NASA’s UAS Integration in the NAS Project will contribute flight-validated data and capabilities that reduce technical barriers related to the safety and operational challenges associated with enabling routine civil UAS access to the NAS.

# INTEGRATED AVIATION SYSTEMS PROGRAM

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| Mandatory Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| 21st Century Clean Transportation Plan | -- | -- | 37.0 | 84.0 | 196.0 | 300.0 | 370.0 |

IASP is supported in part by mandatory funding under a multiagency 21st Century Clean Transportation Plan. This initiative extends beyond the five-year period covered in this document. Full funding for the clean transportation initiative in IASP is $2.1 billion over 10 years. The IASP budget also supported by $55.9 million of mandatory funding in FY 2017 to begin work on an LBFD.

With this request, NASA Aeronautics will begin NAH – a bold new initiative to advance the NASA Aeronautics strategic vision through a continuing series of experimental aircraft and systems demonstrations. This NAH initiative will demonstrate transformative concepts with integrated, advanced technologies that will meet the long-term needs of aviation and sustain U.S. technological leadership. IASP leads the NAH effort that supports the achievement of all six research thrusts over time.

NAH efforts will continue to address innovations in subsonic flight with a new HWB Demonstrator. In FY 2017, NAH initiates the development of a formal preliminary design for a large-scale HWB experimental aircraft. The HWB configuration has been the focus of substantial research and experimentation and represents the most mature concept, ready for flight demonstration and validation. NAH also initiates early design studies for additional experimental aircraft demonstrations focused on other key technology needs, such as very efficient, high aspect ratio wings and transformative approaches to engine integration with the aircraft that enable major reductions in fuel use. The design studies will be coordinated with AAVP ground experiments on key technology enablers. The design studies and ground experiments will lead to a decision to proceed to final design and build of an experimental aircraft at the end of FY 2019.

Over the past decade, fundamental research and experimentation has demonstrated the possibility of supersonic flight with much reduced sonic boom noise. The LBFD X-plane will demonstrate these advancements in flight utilizing a purpose-built experimental aircraft, supporting the development of a sonic boom standard that would allow overland commercial supersonic flight (currently prohibited).

## ACHIEVEMENTS IN FY 2015

### Thrust 3: Ultra-Efficient Commercial Vehicles

NASA's ERA Project concluded its final year of execution, and successfully completed all eight Integrated Technology Demonstrations (ITDs). These ITDs directly support NASA's goal to advance ultra-efficient commercial vehicles flying in the 2020-2025 timeframe. Once implemented, together these ITDs cut fuel burn in half, reduce community noise 42 decibels below current standards, and reduce emissions by 75 percent during take-off and landing. These NASA developed technologies significantly contribute to the aviation community's goal of achieving far more environmentally friendly aircraft without compromising performance.

# INTEGRATED AVIATION SYSTEMS PROGRAM

Two ERA flight experiments took place this year aboard the Boeing 757 ecoDemonstrator flying testbed. The first studied how small jets embedded in an aircraft's vertical tail and blowing air over its surfaces could provide enough force to safely allow smaller tails on future aircraft designs. Doing so would save weight, reduce drag and drop fuel usage up to 0.5 percent – a small number that quickly adds up to big savings. The testing of the active flow control technology during six flights in a variety of configurations and flight conditions, including simulated engine failures, worked as designed, duplicating the results of wind tunnel tests conducted in 2013.

The second demonstration studied how well special coatings worked to prevent sticky bug residue from building up on the leading edge of an airplane wing with the resultant increase in drag. Fewer remains would smooth airflow and help reduce fuel consumption. NASA and Boeing engineers made 15 flights into bug-filled skies near Shreveport Regional Airport testing non-stick wing coatings. Although more testing is required, one of the five coatings tested showed promising results by reducing bug counts and residue about 40 percent.

### Thrust 6: Assured Autonomy for Aviation Transformation

For UAS integration into the NAS, NASA delivered data, analyses, and recommendations based on research that included an integrated flight test series using simulated airspace/traffic, and a live vehicle to inform development of preliminary minimum operational performance standards by the RTCA Special Committee 228 (SC228) on UAS integration into the NAS. The special committee is responsible for developing MOPS for flying UAS in the NAS. NASA researchers provided input including data, analysis, and recommendations based on integrated flight tests involving both simulated and live vehicles traversing airspace and interacting with other aircraft. Research results briefed to the committee for MOPS development included guidance, alerting, human machine interface, aircraft performance, terminology, system specific performance requirements, and equipment test procedures. The RTCA Program Management Council approved this information as a part of the Preliminary MOPS.

UAS activity for FY 2015 wrapped up with the successful demonstration of a prototype Detect-and-Avoid (DAA) system using NASA's remotely piloted Ikhana aircraft. Ikhana made 11 flights over the California high desert involving more than 200 scripted encounters with approaching aircraft. Depending on the specific scenario, either Ikhana detected one or more approaching aircraft and sent an alert to its remote pilot to take action, or Ikhana autonomously took action by flying a programmed maneuver to avoid a collision – an aviation first. The DAA research was designated FT3, the third in a series of flight test campaigns for NASA’s UAS Integration in the NAS project. Knowledge gleaned from the data recorded during this third phase of UAS-NAS flight tests will not only help researchers plan the next phase of flight tests targeted for FY 2016, but will also help inform organizations developing UAS-related operating standards, including RTCA SC228.

## WORK IN PROGRESS IN FY 2016

### Thrust 2: Innovation in Commercial Supersonic Aircraft

As a continuation of the research and technology strategy for Thrust 2 as implemented by the AAVP, NASA will initiate and nearly complete a detailed preliminary design for a low boom demonstrator aircraft. This design will enable the development of an aircraft capable of generating the necessary data to support an overland boom standard for commercial supersonic flight.

# INTEGRATED AVIATION SYSTEMS PROGRAM

### Thrust 3: Ultra-Efficient Commercial Vehicles

Work conducted in the ERA project will culminate in a Closeout Review in FY 2016. This review will describe the culmination of the ERA effort through Phase 2 ITDs as well as the overall benefit realized through N+2 technology investigations conducted and assessed during the 6-year life of the ERA Project.

In FY 2016, NASA will leverage success from the ERA Project, as well as other NASA Aeronautics initiatives, to commence with multiple studies focused on informing the solicitation process for advanced configuration subsonic demonstrator aircraft. In addition to the aircraft configurations themselves, studies will also evaluate candidate technologies as well as novel methods for conducting flight demonstrations.

Also in FY 2016, NASA will continue to capitalize on the successful technologies and benefits born out of the ERA effort. As with ERA, NASA will conduct high-impact collaborations with an early focus on reducing aircraft environmental impacts. NASA will develop integrated system-level flight demonstrations focused on the most promising technologies to assess feasibility of integrated benefits and/or to advance technology readiness levels. During the year, NASA will begin a series of flight demonstrations to both mature and transfer green aircraft technologies to U.S. industry. These technologies include: Ultra-High Bypass Engine Nacelle Technology; X-56 Light Weight Flexible Wing; Adaptive Compliant Trailing Edge Flaps for Noise Reduction; and Landing Gear Noise Reduction. In order to accomplish these technologies, NASA will select the most appropriate assets available (NASA, other Government agencies, industry, or international partners) to support the chosen technology demonstrations. These technologies further capitalize on technologies from the ERA Project, and increasing autonomy in support of the UAS Integration to NAS Project.

### Thrust 6: Assured Autonomy for Aviation Transformation

Automation will continue to transform the civil aviation industry and is a rich area for continued research. NASA seeks to forge applications of automation in aircraft operations and air traffic management, and generate validated data through testing for regulatory bodies. NASA will also develop technologies and concepts that promote safety, reliability, and future economic development. The use of analysis, simulation, and flight testing will further the integration of UAS in the NAS for commercial, science, security, and other uses. In FY 2016, NASA will deliver data, analysis, and recommendations, based on two flight test series with simulated traffic and live vehicles to RTCA SC228 on MOPS for unmanned aircraft systems. This effort is critical to the success of RTCA’s effort and the standards necessary to achieve UAS integration into the National Airspace. Flight Test 4 (FT4) will be the last flight test series for this phase of the UAS in the NAS project. The planned progression of the flight test campaign will see high levels of technology integration and higher complexity of test conditions. The testing will integrate UAS and manned aircraft with ground control stations and air traffic data. The integration of UAS in the NAS will include flight demonstration of detect and avoid, command and control and advanced ground control station display technologies in a flight environment representing the NAS using the Live, Virtual, Constructive, Distributive Environment (LVC-DE).

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

### Thrust 2: Innovation in Commercial Supersonic Aircraft

In line with the continuation of maturation of concepts and technologies through large-scale experiments and flight demonstrations, NASA will start the design/build phase of the new LBFD Project as part of the bold NAH initiative that will support a continuing series of transformative experimental vehicles and systems. Starting the demonstration at this time will work to ensure NASA is in line with the International Civil Aviation Organization's (ICAO) Committee on Aviation Environmental Protection (CAEP) schedule related to aircraft noise and emissions, and more generally to aviation environmental impact.

### Thrust 3: Ultra-Efficient Commercial Vehicles

In FY 2017, PDR of a flight demonstration to validate technologies to improve the performance of Ultra-High Bypass Engine Nacelles will be conducted as part of the FDC Project. An engine nacelle is the housing, separate from the fuselage, which holds engines, fuel, or equipment on an aircraft.

The FDC Project will also continue an impactful collaboration with Aurora Flight Sciences to reduce the aircraft environmental footprint by completing an effort to assess the D8 configuration through completion of a Conceptual Design Review of the D8 aircraft configuration as well as a Preliminary Design Review for the D8 aircraft structure. These reviews are key elements to understand the feasibility and risks associated with pursuing a flight demonstration of this unconventional configuration.

In FY 2017, ACTE II Sub-Project of FDC will complete the Adaptive Compliant Trailing Edge (ACTE) II Noise Reduction Flight experiment. This will verify the noise reduction benefits of the ACTE flap feasibility as shown in flight under the ERA project.

Following completion of a solicitation for the HWB Demonstrator, a contract will be awarded in FY 2017 to commence with preliminary design activities for the HWB that will lead to completion of PDR in FY 2018. In addition, multiple studies associated with advanced concept subsonic aircraft configurations will be completed that inform the solicitation process for one or more Subsonic Demonstrator aircraft. Subsonic Demonstrator contract awards will follow in FY 2018. In addition, NASA will continue to facilitate small flight demonstrations, maintain capabilities that make assets available for flight experiments, and develop/maintain the ARMD flight test roadmap.

### Thrust 6: Assured Autonomy for Aviation Transformation

NASA will extend the UAS in the NAS project through FY 2020 to support FAA and RTCA in the development of Phase 2 MOPS. The goal of phase 2 is to develop MOPS for Detect and Avoid and Command and Control for extended operations of UAS into higher altitude airspace including class D, E and possibly G. NASA will develop performance standards for DAA and satellite communications and perform integrated testing and evaluations.

## Program Elements

### UNMANNED AIRCRAFT SYSTEMS (UAS) INTEGRATION IN THE NATIONAL AIRSPACE SYSTEM (NAS)

In this project, NASA focuses on technologies to enable routine civil operations for UAS of all sizes and capabilities in the NAS. This research aligns with ARMD's Assured Autonomy for Aviation Transformation strategic thrust area. Since many of the current Federal Aviation regulations support a pilot being in the aircraft, they are not directly applicable to UAS. To date, the primary user of UAS has been the military. The technologies and procedures to enable seamless operation and integration of UAS in NAS are vetted by FAA through rule making and policy development as the UAS user base expands.

Specifically, NASA is addressing technology development in several areas to reduce the technical barriers related to safety and operational challenges. The technical barriers include:

- Robust separation assurance algorithms;
- Command and control, and air traffic control communication systems;
- Consistent standards to assess UAS ground control stations; and
- Airworthiness requirements for the full range of UAS size and performance.

NASA will validate data and technology through a series of high-fidelity HITL simulations (e.g., where a human is part of the simulation and influences the outcome) and flight tests conducted in a relevant environment. The project will conduct integrated test and evaluation focusing on three technical challenges: separation assurance, performance standards and certification, and developing a relevant test environment. The project deliverables will help key decision makers in Government and industry make informed decisions, leading towards routine UAS access. In Phase 2 of the Project, the SC228 goal is to develop MOPS for Detect and Avoid, and Command and Control equipment for extended operations of UAS in Class D, E, and perhaps G airspace.

## FLIGHT DEMONSTRATIONS AND CAPABILITIES (FDC)

NASA's FDC Project will validate benefits associated with critical technologies through focused flight experiments. As part of the FDC Project, NASA will demonstrate the feasibility and maturity of new technologies through flight tests, utilizing collaborative partnerships from across the aeronautical industry, and include international partners as appropriate. These demonstrations will typically address technologies that have proven their potential merit through ground based or subscale testing and require results from a realistic flight environment for validation of the benefits.

Through the integrated use of appropriate flight test capabilities and assets, regardless of whether the capabilities and assets are available from NASA, through other Government agencies or industry, the FDC Project will validate benefits associated with critical selected technologies. The flight experiments are campaigns focused on aggressive, success-oriented schedules utilizing the most appropriate set of assets available to accomplish the experimental objectives. While many of the technologies will be at relatively high TRLs, the FDC Project will support all phases of technology maturation.

The FDC Project will utilize specific flight research and test capabilities residing within NASA, including the Dryden Aeronautical Test Range and Simulation and Flight Loads Laboratories at the AFRC, necessary to address and achieve the ARMD Strategic Plan, ARMD Program/Project activities. The Project will also utilize flight research and test capabilities across the U.S. aeronautical industry and international partners as appropriate.

## NEW AVIATION HORIZON (NAH) INITIATIVE

The NAH Initiative will support large scale testing in relevant environments needed to ensure acceptance of new technologies for aircraft and airspace systems by the aviation community. Projects under this

NAH initiative will study, develop, and fund large-scale demonstrations. Features of this new initiative include:

- Develop a series of X-Aircraft and X-Systems demonstrations of integrated concepts and technologies;
- Build from a suite of technologies proven through Ground and Flight Test and integrated into advanced aircraft or system configurations;
- Focus on flight demonstration required to fully understand complex, transformational flight systems, including structures, aerodynamics, propulsion, controls (including human factors and autonomy) and flight dynamics interactions;
- Align with ARMD Strategic Implementation Plan; and
- Develop a NASA-Industry resource sharing partnership approach

## NAH-SUBSONIC DEMONSTRATOR (SD)

The third NAH project is the NAH-Subsonic Demonstrator (SD). The overall goal of the NAH-SD project is to demonstrate the performance and feasibility of advanced, unconventional ultra-efficient configurations through flight-testing. The NAH-SD project will begin by conducting and assessing studies of the anticipated performance of advanced configurations as well as technologies to be included in flight demonstrations. In addition to the studies, NASA will also use technology testing in AAVP to inform decision-making about subsonic flight demonstrator configurations. Once assessments are complete, the most promising configurations will be pursued as standalone flight demonstration projects within NAH.

## NAH-LOW BOOM FLIGHT DEMONSTRATOR (LBFD)

The goal of the NAH-LBFD project is to overcome the sonic boom barrier and open the door for development of a new generation of supersonic civil transport aircraft. The primary objectives of the NAH-LBFD are two-fold: flight validation of design tools and technologies applicable to low sonic boom commercial supersonic aircraft, and creation of community response data that will support the development of a noise-based standard for supersonic overland flight. NAH-LBFD will provide the tools and database that enables regulatory agencies to lift the current prohibition on overland supersonic flight.

## NAH – HYBRID WING BODY (HWB) DEMONSTRATOR

The overall goal of the NAH-HWB project is to demonstrate the performance and feasibility of an ultra-efficient HWB configuration through flight-testing. The NAH-HWB project will leverage substantial research and experimentation, including recent HWB learning from the ERA Project and collaborate with industry to complete preliminary and detail design activities that will lead to producing the HWB Demonstrator, and culminate in the HWB flight test campaign.

# INTEGRATED AVIATION SYSTEMS PROGRAM

## Program Schedule

| Date | Significant Event |
|---|---|
| Sep 2015 | Completed eight successful ITDs, and cumulative impact assessments of Phase 1 and Phase 2 technologies at vehicle and fleet levels |
| Jul 2015 | Delivered data, analysis, and recommendations based on integrated simulations and flight tests to the RTCA Special Committee on MOPS for UAS to support preliminary MOPS development |
| Jan 2016 | Complete close-out activities for the ERA Project |
| Mar 2016 | Begin small fight demos under the FDC Project |
| Jul 2016 | Deliver data, analysis, and recommendations based on integrated simulation and flight test series with simulated traffic or live vehicles to the RTCA Special Committee on MOPS for UAS to support development of the final MOPS |
| Feb 2017 | Conduct D8 CDR/PDR |
| Aug 2017 | Complete PDR of a flight demonstration to validate technologies to improve the performance of Ultra-High Bypass Engine Nacelles |
| Sep 2017 | Complete PDR of a HWB Demonstrator aircraft |

## Program Management & Commitments

| Program Element | Provider |
|---|---|
| UAS Integration in the NAS | Provider: ARC, AFRC, GRC, LaRC<br>Lead Center: AFRC<br>Performing Center(s): ARC, AFRC, GRC, LaRC<br>Cost Share Partner(s): Rockwell Collins, FAA, Dragonfly Pictures, General Atomics, University of North Dakota |
| Flight Demonstrations and Capabilities | Provider: ARC, AFRC, GRC, LaRC<br>Lead Center: AFRC<br>Performing Center(s): ARC, AFRC, GRC, LaRC<br>Cost Share Partner(s): DoD, Air Force Research Laboratory, Lockheed Martin, Flexsys |
| NAH - LBFD | Provider: ARC, AFRC, GRC, LaRC<br>Lead Center: TBD<br>Performing Center(s): ARC, AFRC, GRC, LaRC<br>Cost Share Partner(s): TBD |

# INTEGRATED AVIATION SYSTEMS PROGRAM

| Program Element | Provider |
|---|---|
| NAH - HWB Demonstrator | Provider: ARC, AFRC, GRC, LaRC<br>Lead Center: TBD<br>Performing Center(s): ARC, AFRC, GRC, LaRC<br>Cost Share Partner(s): TBD |
| NAH - Subsonic Demonstrator | Provider: ARC, AFRC, GRC, LaRC<br>Lead Center: TBD<br>Performing Center(s): ARC, AFRC, GRC, LaRC<br>Cost Share Partner(s): TBD |

## Acquisition Strategy

NASA's IASP develops and further matures promising technologies to the integrated system level. This necessitates the use of a wide array of acquisition tools relevant to the appropriate work awarded externally through full and open competition. Teaming among large companies, small businesses, and universities is highly encouraged for all procurement actions.

### MAJOR CONTRACTS/AWARDS

NASA's Aeronautics programs award multiple smaller contracts, which are generally less than $5 million. They are widely distributed across academia and industry. It is anticipated that during FY 2017, awards to support NAH initiatives to design HWB and ultra-efficient Subsonic Demonstrators will be made that are in excess of $5M. In addition, a contract to build the Low Boom Supersonic Demonstrator will be awarded that will be in excess of $5M. All of these design and build contracts will be widely competed through full and open competitions.

### INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | Expert Review | Oct 2015 | The 12-month review is a formal independent peer review. Experts from other government agencies report on their assessment of technical and project risk and/or weaknesses. | The Panels expressed that both the FDC and UAS/NAS Projects were highly relevant and overall in very good shape | Oct 2016 |

# TRANSFORMATIVE AERO CONCEPTS PROGRAM

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | 97.4 | -- | 122.3 | 154.4 | 193.8 | 179.7 | 196.2 |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

**This graphic shows the idea behind the "digital twin" transformative tool – could a computer model be created that predicts how an aircraft will perform over time?**

TACP cultivates multi-disciplinary, revolutionary concepts to enable aviation transformation. ARMD's strategic analysis identified challenges in the global demand for mobility, significant energy and sustainability challenges, and ongoing affordability issues, for which technology can be a key part of the solutions. TACP fosters innovative solutions to these problems, capitalizing on advancements in aeronautics and non-aeronautics sectors to create new opportunities in aviation. The ultimate goal of the program is to knock down technical barriers and infuse internally and externally originated concepts into all six ARMD strategic research thrusts, creating innovation for tomorrow in the aviation system.

Using sharply focused activities, the program provides flexibility for innovators to explore technology feasibility and provide the knowledge base for radical transformation. The program solicits and encourages revolutionary concepts, creates the environment for researchers to become immersed in trying out new ideas, performs ground and small-scale flight tests, allows failures and learns from them, and drives rapid turnover into new concepts. Further, TACP places attention on computational and experimental tools that are critical for supporting development and enabling aviation transformation. Thereby, investments are in never-done-before developments that can provide paradigm-shifting analysis and experimental capability. All of this research is done while aggressively engaging the traditional aeronautics community as well as non-traditional partners.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| Mandatory Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **21st Century Clean Transportation Plan** | -- | -- | 15.0 | 55.0 | 90.0 | 75.0 | 90.0 |

# TRANSFORMATIVE AERO CONCEPTS PROGRAM

Across all ARMD programs, NASA researchers are developing innovative capabilities to advance the strategic thrusts and enable their outcomes. In TACP, new concepts, revolutionary methods, and disruptive technologies are cultivated in support of those strategic thrusts and outcomes. In order to provide a steady inflow of new ideas into the TACP portfolio, parallel, independent research paths are needed. One of those paths will be via the new University Innovation and Challenges Project. In FY 2017, the current Leading Edge Aeronautics Research for NASA (LEARN) Project will be phased out and emphasis will be placed on a university leadership approach. The new project will involve universities independently analyzing the technical barriers inherent in achieving the strategic outcomes and proposing set of multi-disciplinary technical challenges along with supporting activities to address those barriers, and then NASA competitively selecting the most strategic and transformative proposals. The project will also continue to utilize challenges and prizes to the external community to catalyze investments from the aerospace and non-aerospace communities toward solving problems aligned with NASA interests.

TACP is supported in part by funding under a multiagency plan for a 21st Century Clean Transportation Plan. This initiative extends beyond the five-year period covered in this document. Full funding for the initiative in TACP is $0.6 billion over 10 years.

## ACHIEVEMENTS IN FY 2015

NASA completed specific activities in the Convergent Aeronautics Solutions (CAS) Project that started in the previous Aviation Safety Program. In addition, NASA gained specific knowledge supporting the understanding and mitigation of current and future aviation hazards as well as the detection and diagnosis of life-limiting faults in off-nominal turbine engine operation. NASA assembled data supporting algorithms used in ground-based sensors systems for the aviation community to provide terminal area icing weather information. NASA also completed a conceptual design for an advanced sensing system that provides not only the required lightning protection, but also provided damage diagnosis in composite structures. Finally, NASA, in cooperation with other government, manufacturers, and other partners, demonstrated the capability of advanced gas-path sensors and diagnostics systems to detect faults between major inspections by completing a controlled volcanic ash exposure experiment in an operating engine. For the aviation community, this is a major step toward providing in-flight health management capabilities.

NASA explored collaborative program/center processes to incubate and select the best cross-center, multi-disciplinary research activities, leading to the establishment of initial feasibility of the technologies and concepts. NASA researched an initial set of ideas for feasibility, including a distributed electric propulsion (DEP) concept for performance and scalability. It has the promise of significant reductions in emissions and noise that can support the application of lower-carbon propulsion technologies. NASA completed ground testing of the 1st generation DEP wing to validate the high lift computational predictions. Also, NASA began a study of low-cost, fast-turnaround methods for obtaining realistic vehicle performance and flying quality data in flight research; one initial method explored was that of towing an X-plane. These test methods could support future advanced vehicle development with increased probability of success during early design, fabrication, and flight research.

NASA continued developing next-generation, high-performance, computational methods and tools that have the potential to dramatically reduce the cost and error in simulating complex turbulent flows. The Transformational Tools and Technologies Project began a series of wind tunnel test which will result in a unique validation data set to compare against turbulence prediction results obtained using advanced models for a standard test case involving flow separation.

NASA funded new challenging research ideas through the external LEARN Project as well as completing follow-on phases of the most promising research awards by NASA in-house and selected external LEARN teams. Industry and university teams continued several phase two awards, three of which include:

- Plasma-assisted combustor dynamics control to enable ultra-compact, low emission combustors;
- Sensor fusion and cooperative strategy for gust sensing and suppression within formation flight; and
- Innovative nanotube technology to enable practical, multifunctional structure composites with superior mechanical performance. Upon completion, NASA will evaluate the results for incorporation into the existing programs.

## WORK IN PROGRESS IN FY 2016

NASA will advance state-of-the-art aeronautics modeling and simulation capability through improved physics-based tools and methods development. These multidisciplinary tools and methods will enhance the ability to predict and design air vehicles and propulsion systems. Improvements in aerodynamics, combustion, acoustics, and materials modeling capability, and experimental validation of these methods against community-wide standard test cases will also improve prediction capabilities.

NASA will mature new, innovative technologies in materials, sensors, actuators, and measurement techniques to address the needs of future air vehicles and propulsion systems. NASA will facilitate improved vehicle performance and measurement accuracy, higher-temperature application of ceramic matrix composite materials and measurement techniques that can withstand higher temperature environments in addition to the next generation of concepts.

NASA will continue cross-Center, multi-disciplinary research activities, leading to the establishment of initial feasibility of the technologies and concepts across the ARMD strategic research thrusts. One of the activities include determining whether a high voltage, lightweight, efficient power distribution systems could enable hybrid electric aircraft propulsion systems. Another activity looks at understanding how aerodynamics modeling, adaptive controls, sensors, and machine learning can reduce the time to design and test new aircraft configurations. In addition, NASA will evaluate if it is possible to use advances in chemistry and nanotechnology to create multi-functional aircraft structures that can store electrical power. By exploring a computer model that can more accurately predict how a future aircraft will perform over time, this can possibly accelerate its certification while assuring safety and expanding reliability. NASA will also evaluate of the feasibility of an open-standard operating system for smart UAS autonomy apps based on verified, reusable software.

NASA will complete funding new research ideas through LEARN Project via competitive awards to industry and universities. In addition, NASA will begin the University innovation leadership initiative, to leverage independent thinking on high-technical risk, multi-faceted approaches to overcoming strategic thrust barriers. NASA will also utilize challenges and prizes to engage non-aerospace communities of interest as well as traditional partners. NASA will evaluate the most promising ideas to incorporate into existing programs.

# TRANSFORMATIVE AERO CONCEPTS PROGRAM

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA will demonstrate critical turbulence models and numerical methods for separated flows that provide a 40% reduction in predictive error against standard test cases. Current fluid models continue to be unreliable in representing turbulent flow regions (including separated flows). These limitations have prevented the broader use of numerical modeling for aircraft design, leading to higher costs and less than optimal designs. NASA will use these advanced computational models in meeting ambitious fuel efficiency goals associated with fundamentally new aircraft and propulsion systems. NASA's turbulence models are one key contribution to the CFD 2030 Vision, a collaborative effort recently established by leading fluid dynamics experts from government, industry, and academia. NASA will fund the advancement and validation of other breakthrough design tools called for in the CFD 2030 Vision in order to support and enable the technologies and configurations of the ultra-efficient X-planes in the clean air transportation initiative.

NASA will develop high-temperature material systems for turbine engine components that enable a 6 percent reduction in fuel burn while meeting 2700F use temperature and durability metrics. Higher temperature materials reduce the amount of cooling needed in engine turbines, improving fuel efficiency, and reducing emissions. As part of this effort, NASA has been collaborating with a U.S. engine company to advance these high-temperature ceramic matrix composites (CMC) materials. The company plans to incorporate CMCs into the hot section of a new engine that will power the next generation of commercial single-aisle airplanes.

NASA will complete feasibility assessments for several activities within CAS Project. All CAS activities culminate in a feasibility assessment. Given the challenging nature of CAS activities, many technologies will not demonstrate feasibility. NASA will use the results from the assessments to guide future investments and to provide essential knowledge that can benefit all ARMD programs. NASA will prepare for flight-testing of the DEP 2nd generation wing and electric cruise motors. This flight test will assess the feasibility of the DEP concept to provide high-speed cruise efficiency and will provide knowledge for future electric propulsion research investment decisions. NASA will also evaluate a set of "smart apps" for autonomous UASes in flight. If successful, these apps can provide a low barrier to entry for prospective UAS software developers, while also providing capabilities that allow autonomous UAVs to behave like certified pilots. In another activity, NASA will complete feasibility testing of an innovative aircraft design and build concept that merges digital manufacturing, lightweight materials, and novel flight control techniques. This concept has the potential to enable new aircraft designs that are quieter and more fuel efficient, while greatly reducing manufacturing costs.

NASA will begin a new round of investments in early-stage, multi-disciplinary concept research and technology feasibility experiments performed by NASA researchers. These activities will lead to the establishment of initial feasibility of high-potential solutions in low carbon aviation as well as across all the ARMD strategic research thrusts.

# Program Elements

## CONVERGENT AERONAUTICS SOLUTIONS

The CAS Project uses short-duration activities to establish early-stage concept and technology feasibility for high-potential solutions. Internal teams propose ideas for overcoming key barriers associated with large-scale aeronautics problems associated with ARMD's six strategic thrusts. The focus is on merging traditional aeronautics disciplines with advancements driven by the non-aeronautics world to advance innovative solutions to these barriers to open and enable new capabilities in commercial aviation. The teams will conduct initial feasibility studies, perform experiments, try out new ideas, identify failures, and try again. At the end of the cycle, a review determines whether the developed solutions have met their goals, established initial feasibility, and identified potential for future aviation impact. During these reviews, the project considers the most promising capabilities for continued development by other ARMD programs or by direct transfer to the aviation community. In a dynamic environment of new ideas, NASA obtains significant value from the knowledge and widely disseminates it among the aeronautics community at large.

## TRANSFORMATIONAL TOOLS AND TECHNOLOGIES

The Transformational Tools and Technologies Project advances state-of-the-art computational and experimental tools and technologies that are vital to aviation applications in the six strategic thrusts. The project develops new computer-based tools, models, and associated scientific knowledge that will provide first-of-a-kind capabilities to analyze, understand, and predict performance for a wide variety of aviation concepts. Applying these revolutionary tools will enable and accelerate NASA's research and the community's design and introduction of advanced concepts. Examples include the development and validation of new computational tools used to predict complex turbulent airflow around vehicles and within propulsion systems, ultimately leading to greater abilities to predict future vehicle performance in flight. The Project also explores technologies that are broadly critical to advancing ARMD strategic outcomes, such as:

- Understanding new types of strong and lightweight materials;
- Innovative controls techniques; and
- Experimental methods.

Such technologies will support and enable concept development and benefit assessment across multiple ARMD programs and disciplines.

## UNIVERSITY INNOVATION AND CHALLENGES

The University Innovation and Challenges Project will contain a portfolio of disruptive technologies and other entirely new concepts in order to meet the challenging goals established for each strategic thrust established by ARMD. The Project will utilize NASA Research Announcement (NRA) solicitations where university-led teams are asked to assess the most critical technical challenges that must be solved to achieve the SIP strategic outcomes; and to propose independent, innovative research projects to solve those technical challenges, including developing the success criteria, progress indicators, and technical approach. It is expected that multi-faceted solutions to these complex technical challenges will involve high technical risk, multi-disciplinary approaches, industry partnerships, and that they will provided opportunities to work on challenging problems that inspire the next generation of U.S. aeronautics engineers and workforce. The competitively selected research activities will open alternate avenues for accelerated progress by ARMD and the aerospace community toward the strategic outcomes, as well as leveraging new thinking and fostering development of the next generation workforce critical to the long-term development of low carbon aviation.

# TRANSFORMATIVE AERO CONCEPTS PROGRAM

The Project will also utilize challenges and prizes to the broad external community to catalyze external investments toward solving problems aligned with ARMD's strategic interests. Funded challenges and prizes on low carbon air transport systems will be designed to attract and incentivize non-traditional entities (e.g., companies in Information Technology, energy storage/batteries, electric motor manufacturing, etc.).

## Program Schedule

| Date | Significant Event |
|---|---|
| Dec 2015 | Call for FY 2017 proposals from internal teams on large-scale aeronautics problems important to ARMD |
| Mar 2016 | CASTing for FY 2017 Proposals |
| Jul 2016 | Complete single element LDI code validation experimental measurements |
| Sep 2016 | Evaluate Adv RANS & Scale Sims Capability for Prediction Shock Boundary Layer Interactions |
| Mar 2017 | Demo Multiscale Modelling/CMC Materials |
| Jul 2017 | CFD Prediction Assessment Workshop |
| Sep 2017 | Hi Fidelity Fluid Modeling |

## Program Management & Commitments

| Program Element | Provider |
|---|---|
| CAS | Provider: ARC, GRC, LaRC, AFRC<br>Lead Center: GRC<br>Performing Center(s): ARC, GRC, LaRC, AFRC<br>Cost Share Partner(s): JOBY Aviation, PCKrause & Associates, National Institute of Aerospace, Boeing, AFRL, ESAero, Tecnam MTProp, Launch Point, Cape Air, Straight Up Imaging, DoT Volpe, Moog Inc., IDEO, Idea Couture, Tecolote Research Inc., AFRL, WP AFB, Universities |
| Transformational Tools and Technologies | Provider: ARC, GRC, LaRC, AFRC<br>Lead Center: GRC<br>Performing Center(s): ARC, GRC, LaRC, AFRC<br>Cost Share Partner(s): Boeing, Pratt & Whitney, Rolls Royce, Honda, UTRC, ESI, Blue Quartz Software, General Electric, FAA, AFRL, U.S. Air Force, U.S. Army, U.S. Navy, Defense Advanced Research Projects Agency (DARPA), Distributed Engine Controls Working Group Consortium, Honeywell, BAE Systems, UTC Aerospace Systems, Ohio Aerospace Institute, U.S. small businesses and universities |

# TRANSFORMATIVE AERO CONCEPTS PROGRAM

| Program Element | Provider |
|---|---|
| University Innovation and Challenges | Provider: N/A<br>Lead Center: HQ<br>Performing Center(s): N/A<br>Cost Share Partner(s): TBD |

## Acquisition Strategy

The research conducted through TACP activities will use a wide array of acquisition tools relevant to the research objectives including external solicitations through full and open competitions including challenges and prizes.

### MAJOR CONTRACTS/AWARDS

TACP awards a range of contracts, from multiple small contracts less than $1 million in total, up to $2 million per year. They are widely distributed across academia and industry.

### INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | ARMD Mission Program Directors | No previous review | Review of initial CAS Project activities to determine whether they have met their goals, established initial feasibility, and identified potential for future aviation impact. | Expected result is the identification of the promising capabilities for further development by other ARMD programs or for direct transfer to the aviation community. | TBD |
| Perform-ance | Expert Review | Nov 2015 | The 12-month review is a formal independent peer review. Experts from other Government agencies report on their assessment of technical and programmatic risk and/or project weaknesses. | Received expert feedback on project improvement from the panel members. Determined that the project(s) made satisfactory progress in meeting technical challenges and met all annual performance indicators. | Nov 2016 |

# SPACE TECHNOLOGY

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Agency Technology and Innovation | 31.3 | -- | **34.3** | 35.0 | 35.7 | 36.4 | 37.1 |
| SBIR and STTR | 190.7 | -- | **213.0** | 213.2 | 213.5 | 213.8 | 213.8 |
| Space Technology Research and Development | 378.3 | -- | **579.4** | 456.2 | 469.3 | 482.7 | 496.6 |
| **Total Budget** | **600.3** | **686.5** | **826.7** | **704.4** | **718.5** | **732.9** | **747.5** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

## SPACE TECHNOLOGY

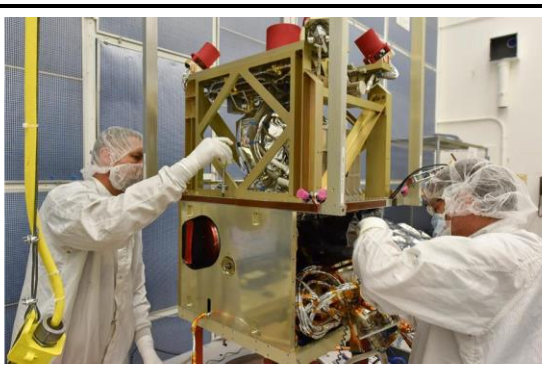
# FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Agency Technology and Innovation | 31.3 | -- | **34.3** | 35.0 | 35.7 | 36.4 | 37.1 |
| SBIR and STTR | 190.7 | -- | **213.0** | 213.2 | 213.5 | 213.8 | 213.8 |
| Space Technology Research and Development | 378.3 | -- | **579.4** | 456.2 | 469.3 | 482.7 | 496.6 |
| **Total Budget** | **600.3** | **686.5** | **826.7** | **704.4** | **718.5** | **732.9** | **747.5** |
| Change from FY 2016 | | | **140.2** | | | | |
| Percentage change from FY 2016 | | | **20.4%** | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*



**Green Propellant Propulsion Payload installed on to its spacecraft bus. NASA, the U.S. Air Force (USAF) and Ball Aerospace & Technologies Corp. of Boulder, Colorado, are collaborating on the Green Propellant Infusion Mission, which seeks to improve overall propellant efficiency while reducing the handling concerns associated with the highly toxic fuel, hydrazine. Aerojet Rocketdyne developed the thrusters. The space mission also strives to optimize performance in new hardware, system and power solutions while ensuring the best value for investment and the safest space missions possible. The Green Propellant Infusion Mission is scheduled to launch in late 2016.**

Space Technology conducts rapid development and infusion of transformative space technologies that increase the Nation's capabilities in space and enable NASA's missions. Space Technology improves our ability to access and travel through space; operate satellites in Earth orbit and far beyond; land more massive systems (such as rovers, habitats, cargo, and eventually people) more accurately in more locations throughout the solar system; live and work in deep space and on planetary bodies; and transform our ability to observe the universe and answer profound questions in earth and space sciences.

NASA leverages the shared interests of stakeholders, customers, and partners from across the nation to develop technology that dramatically enhances current U.S. space capabilities by increasing performance, reducing technological risk, and increasing affordability and reliability. This includes technologies that advance the U.S. space industry, other government agencies, NASA's future science missions, and human spaceflight endeavors beyond low Earth orbit. To advance these critical technologies, NASA sources technology from the entire pool of potential technology suppliers: industry, academia, small businesses, other government agencies, individual entrepreneurs, and NASA

Centers. By engaging the brightest minds on the toughest technological challenges, NASA spurs innovation throughout the aerospace enterprise.

NASA's Office of the Chief Technologist (OCT) coordinates the Agency's overall technology portfolio to identify needs. The Chief Technologist also helps programs work together, and seeks to minimize unnecessary duplication of effort. This office leads NASA technology transfer and nurtures partnership opportunities with a wide range of users to ensure the Nation realizes the full value of these development efforts.

American technological leadership is vital to our national security, economic prosperity, and global standing. The United States' continued economic leadership is, in part, due to the technological investments made in earlier years, through the work of the engineers, scientists, and elected officials who had the wisdom and foresight to make the investments our country required to emerge as a global technological leader. That commitment accelerated the economy with the creation of new industries, products, and services that yielded lasting benefits. A technology-driven NASA will continue to fuel our Nation's economic engine for decades to come.

For more on Space Technology, go to: http://www.nasa.gov/spacetech.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| | Actual | Enacted | Request | Notional | | | |
|---|---|---|---|---|---|---|---|
| **Mandatory Funding (in $ millions)** | **FY 2015** | **FY 2016** | **FY 2017** | **FY 2018** | **FY 2019** | **FY 2020** | **FY 2021** |
| **Space Technology Research and Development** | -- | -- | **136.1** | -- | -- | -- | -- |

Like many elements of the Administration's FY 2017 R&D priorities, Space Technology Programs are supported in part by mandatory funds. The mandatory investment includes $27.3 million for Game Changing Developments (GCD) and $108.8 million for Technology Demonstration Missions (TDM), including Restore-L. Restore-L has been transferred from the International Space Station (ISS) Research program in the Space Operations account, and added as a Technology Demonstration Mission as specified in P.L. 114-113, the Consolidated Appropriations Act, 2016.

## ACHIEVEMENTS IN FY 2015

Space Technology completed an Instrument Accommodation Review and started Phase B for development of an oxygen production system for demonstration on the Mars 2020 mission, designed to convert carbon dioxide from the Mars atmosphere to oxygen with 99.6 percent purity. The Mars Oxygen In-Situ Resource Utilization (ISRU) Experiment (MOXIE) was competitively selected as part of the Mars 2020 Investigations Announcement of Opportunity (AO). This precursor effort, conducted in collaboration with the Human Exploration and Operations Mission Directorate (HEOMD) and Science Mission Directorate (SMD), will verify that in ISRU technologies can produce oxygen at Mars to supply both human breathing needs as well as propellant oxidizer for Mars ascent rockets. Eventually, this technology will be used to send people, science samples, and equipment back into space for their trip back to Earth.

# SPACE TECHNOLOGY

To enable more capable spacecraft, Space Technology completed flight hardware for a variety of small-scale, in-space technology demonstrations, including laser communications and multi-point science observations using CubeSats, and a suborbital demonstration of a small Earth return capsule. NASA is sharing the data and insights gained from these technology efforts widely across the aerospace industry to ensure infusion into future spacecraft designs. In addition, Space Technology completed risk reduction activities for two solar array designs with half of the mass and one-third of the packaging volume compared to the best current arrays. One of the arrays is being transitioned into a major commercial spacecraft manufacturer's product line.

The Low Density Supersonic Decelerator (LDSD) project conducted a second supersonic flight demonstration of a ring-sail parachute, a supersonic inflatable aerodynamic decelerator, and inflatable ballute. The ballute and supersonic inflatable decelerator were successfully demonstrated for the second time, but the parachute did not survive after full inflation. However, this flight test provided a one-of-a-kind set of observations that will have a critical impact on our understanding of the deployment dynamics for supersonic parachutes and inform future parachute development efforts.

In response to feedback from the National Academies and industry, Space Technology kicked off several new competitive solicitations in 2015, using innovative partnership strategies. Several of the solicitations targeted improving the Nation's ability to access and travel through space. Technologies sought in these solicitations included thrusters and power processing electronics for flight demonstration of a high power solar electric propulsion (SEP) system. The Space Technology Mission Directorate (STMD) also released two solicitations and made selections to establish public private partnerships with the U.S. aerospace industry. The Tipping Point solicitation, which required a minimum of 25 percent industry cost sharing, seeks to advance technologies for: robotic in-space manufacturing and assembly of spacecraft and space structures; low size, weight and power instruments for remote sensing applications; small spacecraft attitude determination and control sensors and actuators; and small spacecraft propulsion systems. A technology is considered at the tipping point if an investment in a demonstration of its capabilities would result in a significant advancement of the technology's maturation, high likelihood of infusion into a commercial space application, and significant improvement in the ability to successfully bring the technology to market. The second solicitation was an Announcement of Collaborative Opportunity that will establish partnerships between industry and the NASA Centers through non-reimbursable Space Act Agreements to advance emerging space technology system capabilities in nano-satellite and suborbital reusable launch systems development, thermal protection system materials and systems development; green propellant thruster technology qualification; and small, affordable, high performance liquid rocket engine development.

In addition, NASA continues to invest in the Nation's small businesses with the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs. SBIR/STTR leverage technology solutions developed by small businesses to meet critical Agency and industry needs in areas such as robotics, propulsion, and avionics. A SBIR Phase III contract to develop a deployable fresh-food production system called VEGGIE was used by astronauts on the ISS to grow red romaine lettuce, the first ever space-grown crop, in July 2015

OCT released the draft Technology Roadmaps for public review and comment. These roadmaps will serve as the foundation for the FY 2016 update of NASA's Strategic Technology Investment Plan (STIP), which the Agency uses to prioritize technology development.

# SPACE TECHNOLOGY

NASA's commercial partnership activities include Flight Opportunities, Centennial Challenges, and Regional Economic Development. NASA will develop a more integrated commercial partnership strategy in FY 2016 that will align Flight Opportunities, Centennial Challenges, SBIR/STTR commercial readiness program; Technology Transfer; and Regional Economic Development partnerships consistent with the Lab-to-Market Cross-Agency Priority Goal.

## WORK IN PROGRESS IN FY 2016

Space Technology will continue to develop critical technologies to improve access to and travel through space to benefit both NASA and commercial space endeavors, and enable future missions for new scientific discoveries. This includes initiating development of high-power SEP subsystems, making progress toward a full system demonstration as part of the Asteroid Redirect Robotic Mission (ARRM). Like high-power SEP, technologies developed by Space Technology will benefit the broader aerospace industry and other government agency needs. Examples include further progress of high performance spaceflight computing hardware, robotics for extreme environments, and advanced manufacturing capabilities with government and industry partners.

Furthermore, Space Technology will launch the first flight demonstration of the AF-M315E propellant in the Green Propellant Infusion Mission (GPIM) with in partnership with the USAF, Aerojet Rocketdyne, and Ball Aerospace. This mission will validate this new safer propellant formula as part of an integrated propulsion system. On successful demonstration, the propellant and propulsion system will provide industry with a safer and better-performing alternative to highly toxic hydrazine for use on future space missions. The fuel has the potential to offer many advantages for future missions, including longer mission durations, additional maneuverability, increased payload capacity, and simplified launch processing. In addition, use of this fuel promises to eliminate post mission remediation costs by removing the need to clean up toxic waste at launch and processing sites. This mission also includes first-time flight for a novel thermal insulation material developed by Aspen Aerogels, a small business located in Massachusetts.

Space Technology will conduct an in-space demonstration of its new Deep Space Atomic Clock (DSAC). This new atomic clock provides enhanced navigation accuracy, increased science data bandwidth, and improved gravitational measurements necessary for future planetary science and exploration missions. For example, this technology could enable understanding of Europa's under-ice and liquid water oceans, where precise gravitational measurements are essential to determining the make-up of Europa's surface. In addition, the new atomic clock could provide next-generation GPS satellites with dramatically improved navigational accuracy and time-keeping stability. Space Technology will also initiate development of foundational technologies and studies to advance nuclear thermal propulsion systems that could ultimately provide a rapid in-space transportation capability.

Beginning this year, Space Technology will provide budget and manage the Restore-L mission, an element of the In-Space Robotic Servicing project previously managed by the ISS Research organization. The directorate will determine project requirements, required cost phasing, and a launch readiness date for Restore-L, a mission in formulation that will demonstrate the servicing of a U.S. government satellite in low-Earth orbit. Restore-L will complete a Mission Concept Review (MCR) followed by a Key Decision Point (KDP) A in 2016.

Space Technology will mitigate development risks associated with a Deep Space Optical Communication (DSOC) system capable of order of magnitude greater data rates and complete Technology Readiness

Level 6 (TRL 6) demonstration for infusion into the Discovery 2014 mission. GCD will deliver two coronagraph technologies for Wide Field Infrared Survey Telescope/Astrophysics Focused Telescope Assets (WFIRST/AFTA) consideration that will enable direct, multi-spectral imaging of exoplanets if adopted.

In agreement with the National Academies' recommendations, Space Technology will continue to prioritize transformational technologies and early-stage innovations by utilizing approximately 500 awards to small businesses, private innovators, and academia to spark new ideas for the benefit of U.S. aerospace and high tech industries, and to fuel the space technology pipeline. Space Technology will finalize awards with the aerospace industry to advance technologies at the tipping point and support demonstrations on the ground or in-space of selected technologies.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

FY 2017 STMD activities will continue to prioritize early stage investments that offer the opportunity for transformative technology development, increasing funding to levels consistent with the National Academies recommendation in their 2012 report "NASA Space Technology Roadmaps and Priorities" of 10 percent of the Directorate's investment portfolio with a focus on transformational technologies, such as robotics and autonomous systems, integrated photonics, and advanced materials.

Space Technology will continue work to develop electric propulsion subsystem hardware, based on awards to be made in mid FY 2016, to support the ARRM mission System Design Review (SDR). The Laser Communications and Relay Demonstration (LCRD) project will complete its Critical Design Review (CDR) and KDP-C, and will initiate hardware fabrication to support a late FY 2019 launch readiness date.

Following up on pre-formulation activities in FY 2016, the in-space robotics servicing team will refine the requirements and goals of the Restore-L, a technology demonstration mission capable of servicing a U.S. government satellite in low Earth orbit. STMD, partnering with HEOMD and SMD, will start Phase B before the end of FY 2017.

The directorate will invest in high-priority GCD technologies to enable Mars and Outer Planetary exploration, including high performance spaceflight computing, all terrain robotics, extreme environment solar power, and advanced materials (Bulk Metallic Glass) to improve rover mobility performance at low temperatures. Space Technology teams will also be taking steps to enable more efficient spaceflight by developing improved nuclear fuels to support potential future nuclear thermal propulsion efforts.

After launch in the second quarter of FY 2017 (at the earliest), GPIM will validate an alternative to conventional chemical propulsion systems for next-generation spacecraft, enabling adoption of the alternative propellant technology by commercial spaceports operating across the U.S. and leading to safer, faster, and much less costly launch operations in the future.

Also planned for launch in FY 2017 Quarter 2, DSAC will validate a miniaturized, ultra-precise, mercury-ion atomic clock that is orders of magnitude more stable than today's best navigation clocks. This technology holds the promise to revolutionize deep-space navigation and gravity science, and improve the accuracy of the GPS satellites American citizens and industries depend on every day.

# SPACE TECHNOLOGY

Space Technology will initiate focused Entry Descent and Landing (EDL) technology investments, based on the outcome of a systems study, as a follow-on to the LDSD project.

Space Technology will also initiate a new technology demonstration project, DSOC, to provide high bandwidth communications that will enable future deep space exploration of the solar system. DSOC hardware will be provided as Government Furnished Equipment (GFE) to SMD's Discovery Program, and will be demonstrated on a Discovery 2014 mission.

## Programs

### AGENCY TECHNOLOGY AND INNOVATION

This program supports OCT, which provides the strategy and coordination that guide NASA's technology and innovation activities. OCT documents and analyzes NASA's technology investments and tracks progress, ensuring alignment with the Agency's Strategic Plan. OCT leads technology transfer and technology commercialization activities, extending the benefits of NASA's technology investments so they have a direct and measurable impact on daily life. The office employs principles that encourage partnerships, technology use, and commercialization. This ensures that NASA technologies energize the commercial space sector and provide the greatest benefit to the United States.

### SBIR AND STTR

SBIR and STTR continue to support early-stage research and mid-TRL development, performed by small businesses through competitively awarded contracts. These programs produce innovations for both government and commercial applications. SBIR and STTR provide the high technology, small business sector with opportunities to develop space technology for NASA and commercialize those NASA-funded technologies that have the potential to address national needs in the aerospace industry and other sectors.

### SPACE TECHNOLOGY RESEARCH AND DEVELOPMENT (STR&D)

Space Technology Research and Development (STR&D) develops and demonstrates near-term and far-reaching technological solutions and enhancements, making NASA's missions more capable, affordable, and reliable. STR&D includes NASA Innovative Advanced Concepts (NIAC), Space Technology Research Grants (STRG), the Center Innovation Fund (CIF), GCD, TDM, Small Spacecraft Technology (SST), Centennial Challenge, and Flight Opportunities. These projects provide opportunities to work with various technical communities at the appropriate levels of development for each stage of the technology maturation process. Through these projects within STR&D, Space Technology develops the transformative, broadly applicable technologies necessary for NASA's future science and exploration missions while supporting the space technology needs of other U.S. government agencies and the commercial space sector.

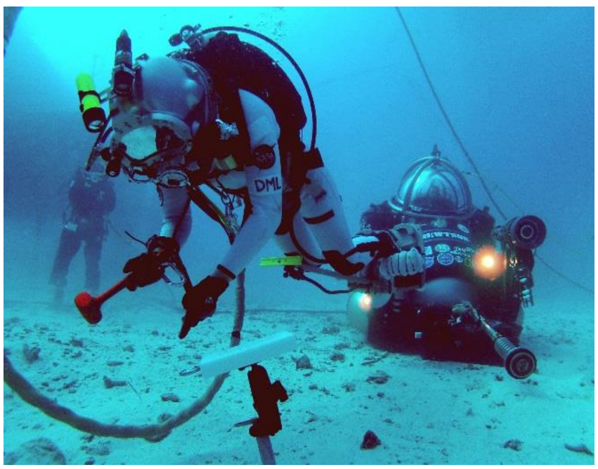
# AGENCY TECHNOLOGY AND INNOVATION

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Total Budget | 31.3 | -- | 34.3 | 35.0 | 35.7 | 36.4 | 37.1 |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**NASA astronauts practice simulated space maneuvers on the ocean floor during NASA Extreme Environment Mission Operations 16 (NEEMO 16) in 2012. They took a three-minute Psychomotor Vigilance Task (PVT) test to help refine the test's algorithm for use in orbit. Pulsar Informatics Inc. has commercialized the PVT and sells it to government and businesses, which use it to monitor behavioral alertness.**

OCT serves as the NASA Administrator's principal advisor on matters concerning Agency-wide technology policies and programs. Agency Technology and Innovation supports OCT's efforts, which provide the strategy and leadership that guide NASA's technology and associated open innovation activities. The office performs an agency-level technology coordination role, working with the NASA mission directorates and field centers to align the Agency's technology investments to mission requirements while filling technology gaps, anticipating future needs, and minimizing duplication of effort.

Through OCT, NASA responds to the legislative requirements and Administration priorities to promote technology transfer, including commercialization of technologies that emerge from NASA's research and development activities. As part of this work, OCT documents and communicates the benefits of NASA technology investments to the Nation through various mechanisms, including the media and publications, such as Spinoff. NASA's technologies provide advanced capabilities, new tools, equipment, and solutions for industry. This spurs economic growth, creates new markets, increases competition in U.S. industry, and maintains U.S. global technological leadership.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

There are no major changes in FY 2017.

## ACHIEVEMENTS IN FY 2015

In FY 2015, NASA released the Agency's updated technology roadmaps, laying out the promising new technologies that will help NASA achieve its aeronautics, science, and human exploration missions for the next 20 years, including the Agency's journey to Mars. The Agency released a Request for Information, seeking public comment on the draft roadmaps to increase awareness, generate innovative solutions for space exploration and scientific discovery, and inspire public involvement in America's space program. Input received from the public was incorporated into the roadmaps. NASA posted the final roadmaps to the Agency's website in July 2015. The roadmaps are a key part of NASA's STIP that lays out the strategy, guiding principles and priorities for developing technologies that are essential to NASA's mission and help achieve national goals.

NASA achieved a significant milestone with the release of the Technology Portfolio System (TechPort) to the public in FY 2015. TechPort is NASA's comprehensive resource for locating information about NASA-funded technology development activities. NASA is the first federal agency to develop and release such a system in support of the Administration's Open Government initiative: http://techport.nasa.gov.

NASA's Technology Transfer Program simplified access to our technology portfolios with a searchable portal that provides easy access to over 1,200 of the Agency's licensable, patented technologies. Organized by technical area, the site is populated with standardized data sheets, showing the benefits, applications, and readiness level of each technology. Users can also search NASA's software catalog, with over 1,000 software programs developed by NASA engineers, available to industry at no cost. In FY 2015, NASA also introduced our software repository, the backend inventory of the catalog, which allows users to complete the agreement forms and download software in just minutes. These activities resulted in a significant increase in the amount of technology that NASA has transferred into the hands of American businesses: a 53 percent increase in patent licensing over FY 2014 (and a progressive year-after-year increase since 2011 equal to 300 percent over that year) and a 24 percent increase in software release; again, with a progressive increase year-after-year in which 2015 doubled what was accomplished in 2011).

The Asteroid Grand Challenge completed a Research Opportunities in Space and Earth Sciences (ROSES) call to develop open source tools to support expanded amateur astronomer completion of light curve analysis: ran a successful asteroid digital badging pilot with middle school students; saw the operation of a user-built 3D printed telescope by students in a township in South Africa; and the launch of a brand new volunteer built web interface for easier access to existing asteroid data. The Expert and Citizen Assessment of Science and Technology pioneered a method, the first in the U.S. government, for meaningful public engagement by conducting two facilitated in-person forums and one online forum to gather general public value around asteroids and exploration.

## WORK IN PROGRESS IN FY 2016

NASA is working with an external organization to complete an independent review of the Technology Roadmaps, and finalize the NASA STIP. The updated STIP will include the prioritization and guiding principles for NASA's technology portfolio, and, as done in FY 2012, the NASA Advisory Council and other government organizations will review the portfolio plan. NASA will also develop and pilot a new method to track infusion of NASA-developed technology into its missions and ground activities. This will enable the Agency to verify the number of NASA-developed technologies that are used by NASA and to determine what types of new technologies are used for more than one NASA purpose.

The Asteroid Grand Challenge has partnered with Verizon Wireless for development of an asteroid hunter mobile application that will enable citizen scientists to assist NASA in classifying asteroid data. The beta of the application will be released to the public in FY 2016. The Grand Challenge will also fund two proposals from the ROSES call, and we are exploring a summer program that engages private sector technology firms to address specific scientific challenges for asteroid characterization.

The Technology Transfer Program is implementing a licensee monitoring system to streamline, augment, and automate intellectual property and license portfolio management. OCT is in the process of standardizing processes across the field centers and writing requirements for development of this tool. The resulting system will be an upgrade to the existing relational database and workflow management tool, the NASA Technology Transfer System, simplifying the technology transfer process for end users. In addition, with StartUp NASA, a new initiative, NASA is encouraging the growth of high tech businesses and advancing American innovation by offering start-up companies access to the patent portfolio at no up-front cost. This initiative helps address two typical problems start-ups face: raising capital and securing intellectual property rights.

### KEY ACHIEVEMENTS PLANNED FOR FY 2017

Strategic Technology Integration will execute an initiative across seven centers to encourage and track infusion of NASA-developed technology by NASA missions and other NASA user groups. The Technology Transfer Program will develop, launch, and migrate all Agency licensing activities to an online patent licensing portal.  Additionally, the Technology Transfer Program will investigate a partnership with the National Science Foundation's Innovation Corps to further catalyze the engagement of local university teams in technology transfer and innovation.

## Program Elements

### OFFICE OF THE CHIEF TECHNOLOGIST (OCT)

OCT provides the strategy, leadership, and coordination that guide NASA's technology and associated innovation activities. OCT accomplishes this through four primary functions:

- Strategic Technology Integration develops policy, requirements, and strategy for NASA's technology development activities in support of the Chief Technologist and coordinates integration with NASA mission directorates, other government agencies, and external organizations. These efforts help to identify priorities, needs, technology development opportunities, and activities that assist NASA in achieving its goals and enable NASA to benefit from cross-agency technological advancements.
- Technology Transfer provides Agency-level management and oversight of NASA-developed and NASA-owned intellectual property, and manage transfer of these technologies to external entities. Activities include active collection and assessment of all NASA inventions, strategic management and marketing of intellectual property, negotiation and management of licenses, development of technology transfer-focused partnerships, and the tracking and reporting of metrics related to these activities (i.e. numbers of new inventions, patents, licenses, cooperative research and development agreements, and software use agreements).
- Prizes and Challenges provides Agency-level leadership and coordination of NASA's organizations that conduct prizes and challenges to spur innovation and increase the number and type of individuals participating in innovation activities. NASA uses prizes and competitions to provide technology breakthroughs that lower mission costs and strengthen expertise to develop

## AGENCY TECHNOLOGY AND INNOVATION

solutions for tomorrow. This activity includes leadership of the Asteroid Grand Challenge, which focuses on finding all asteroid threats to human populations and knowing what to do about them.

- Emerging Space provides analytical support to Agency decision-makers concerning the rapid growth of national and international entrepreneurial space communities, their technology needs, and opportunities for NASA to develop or transfer technologies that will facilitate their growth in the emerging space sector. Activities include monitoring commercial activities, evaluating historical trends, investigating current technology needs, coordinating collaboration discussions, and fostering activities that benefit new markets and the fullest use of space for commercial purposes. As a part of this effort, NASA supports research grants in economic analysis related to emerging space activities in order to strengthen optimizing technology investments.

For more on the Office of the Chief Technologist, go to: http://www.nasa.gov/offices/octt

# SBIR AND STTR

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **190.7** | **--** | **213.0** | **213.2** | **213.5** | **213.8** | **213.8** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**Orbital Technologies partnered with Kennedy Space Center (KSC) to create a plant growth system now used on the International Space Station. The system employs light emitting diodes, which are highly efficient and long lasting and radiate hardly any heat. ORBITEC received a Phase III contract to develop a deployable fresh-food production system called VEGGIE. Astronauts used the system to grow red romaine lettuce and sampled the first ever space-grown crop in July 2015.**

NASA's SBIR and STTR programs leverage the Nation's innovative small business community to support early-stage research and development. These programs provide the small business sector with an opportunity to compete for funding to develop technology for NASA, and to commercialize that technology to spur economic growth. The Agency actively works to facilitate the infusion of NASA-funded SBIR and STTR technologies into its missions and projects. Research and technologies funded by SBIR and STTR contracts have made important contributions to the Agency's mission.

Examples of these activities include 3D printing to support in-space manufacturing, adaptive bio-inspired navigation to support exploration of planetary environments, and gravity mapping of asteroids. The SBIR and STTR programs are investing in new sensor technology, novel robotics concepts, affordable methods of access to low-Earth orbit, and increasingly flexible and adaptable spacesuit designs that may one day be utilized by NASA's science and exploration missions. Elsewhere, SBIR and STTR developed technology will be able to support emergency operations in the face of natural disasters by helping develop Earth science applications tools that will enable real-time collaboration between first responders and storm forecasters.

NASA issues annual SBIR and STTR program solicitations, setting forth a substantial number of topic areas open to qualified small businesses. Both the list and description of topics are sufficiently comprehensive to provide a wide range of opportunities for small business concerns, research institutions, and universities to participate in NASA's research and development programs. There are three phases for SBIR and STTR funding awards. Phase I awards give small businesses the opportunity to establish the scientific, technical and commercial merit, and feasibility of the proposed innovation in fulfillment of NASA needs. The most promising Phase I projects are awarded Phase II contracts through a competitive selection process, based on scientific and technical merit, expected value to NASA, and commercialization potential. Phase II awards focus on the development, demonstration, and delivery of the proposed innovation. Phase II Enhancement (II-E) and Phase II eXpanded (II-X) support advancement of innovations developed under Phase II. Phase III supports the commercialization of innovative technologies, products, and services that result from a Phase I or Phase II contract. Commercialization includes further development of technologies and getting feedback to discover infusion opportunities into NASA programs, other government agencies, or the private sector. Phase III contracts receive funding from sources other than the SBIR and STTR programs and may be awarded without further competition.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

The SBIR and STTR programs reauthorization annually increases the required rate of investment for each program relative to extramural Agency R&D beginning in FY 2012 and continuing through FY 2017. In accordance with the SBIR/STTR Reauthorization Act of 2011 (Public Law 112-81, https://www.congress.gov/bill/112th-congress/house-bill/1540/text), NASA will increase the SBIR investment by 0.2 percent to 3.2 percent of Agency extramural R&D. STTR funding will remain at 0.45 percent of the Agency's extramural R&D.

## ACHIEVEMENTS IN FY 2015

- In FY 2015, SBIR made 461 awards (532 total awards for SBIR/STTR), of which 332 were for Phase I and 129 were for Phase II contracts. These SBIR contract awards were for 327 firms, across 39 different states. These awards included technologies to enable in-space life support and habitation systems, future telescopes and observatories, technologies that generate power and store energy within the space environment, and support electric propulsion.
- In FY 2015, STTR made 71 STTR awards, of which 50 were for Phase I, and 21 were for STTR Phase II contracts. These STTR contracts were awarded to 55 firms in 18 states, collaborating with universities and research institutions to develop technologies for future NASA missions.
- The program participated in eight outreach events, which included technical exchanges and face-to-face summits. These summits support companies as they look to transition beyond Phase II funding.
- The Phase 2-X program proved quite successful as the SBIR/STTR program provided a 2:1 match of funds invested by a NASA program or project to foster infusion. The SBIR/STTR program awarded 31 Phase II-E/X awards totaling $6.18M in SBIR/STTR contributions and $5.36M in matching contributions (non SBIR/STTR funds). SBIR firms awarded Commercial Readiness Program (CRP) funding in FY 2015 will leverage $10.5M in external funding and $5.39M in committed SBIR/STTR funds. SBIR/STTR CRP investment to date totals $9M.
- SBIR and STTR technologies continue to support numerous Space Technology projects, including providing critical self-supporting multi-layer insulation into the GPIM (Aspen Aerogels), a cryocooler design for eCryo (Madison CryoGroup LLC.), and compact Iodine Hall Thrusters (Busek Company Inc.). Agency CRP activities are in place and continue from FY 2015 in the areas of Optics Microscopes for NASA Pop-up Robots (Distant Focus Corp.), Instrument Laser Transmitters (Fibertek), Affordable and Ultralight Blanket Electrical Subsystems (Deployable Space Systems), and several others.

## WORK IN PROGRESS IN FY 2016

- After working with the mission directorates and centers to identify subtopics for the annual solicitations, Space Technology released the annual SBIR and STTR solicitations in November

# SBIR AND STTR

2015 and expects to award new Phase I selections in the third quarter. Phase II selections, as a follow-on from Phase I awards made in FY 2015, will occur in the second quarter. Topics from these solicitations include solid and liquid waste management for human spacecraft, spectroscopy technology and instrumentation, and launch and in-space propulsion technologies.
- Space Technology will continue to refine its implementation of CRP technologies, following evaluation of the FY 2014-2015 pilot effort.

### KEY ACHIEVEMENTS PLANNED FOR FY 2017

- The SBIR and STTR Programs will continue to work with the mission directorates and centers to identify subtopics for the annual solicitations. Space Technology plans to release the annual SBIR and STTR solicitations, and award new Phase I and Phase II selections, SBIR/STTR Program will include small satellite technology as a new topic to address the needs of academic and the commercial small satellite community with a goal of five percent of SBIR/STTR program funding.
- Space Technology plans to continue to support its post Phase II CRP technology investment through FY 2017, and will partner with NSF's I-Corps program to train NASA's SBIR recipients in the commercialization process.

## Program Elements

### SBIR

The SBIR program was established by statute in 1982 and was reauthorized in 2011 to increase research and development opportunities for small business concerns. The program stimulates U.S. technological innovation, employs small businesses to meet federal research and development needs, increases the ability for small businesses to commercialize innovations they derive from federal research and development, and encourages and facilitates participation by socially disadvantaged businesses. In FY 2017, the SBIR program is supported at a level of 3.2 percent of NASA's extramural research and development budget. In FY 2017, the maximum value for an SBIR Phase I contract will be $125,000 for a period of performance of six months. For Phase II, the maximum total value of an SBIR award will be $750,000 over a 24-month period of performance. NASA also supports Phase II Enhancement (II-E) contract options with incentives for cost sharing to extend the research and development efforts of the current Phase II contract. In addition, Phase II eXpanded (II-X) contract options further mature innovations developed under Phase II via an extension of research and development efforts to current Phase II contracts.

### STTR

The STTR program was established by statute in 1992 and was reauthorized in 2011 to award contracts to small business concerns for cooperative research and development with a non-profit research institution, such as a university. NASA's STTR program facilitates transfer of technology developed by a research institution through the entrepreneurship of a small business, resulting in technology to meet NASA's core competency needs in support of its mission programs. Modeled after the SBIR program, STTR is funded based on 0.45 percent of the NASA extramural research and development budget. In FY 2017, the maximum value for an STTR Phase I contract is $125,000 for a period of performance of twelve months. For Phase II, the maximum total value of an STTR award is $750,000 over a 24-month period of performance. Phase II-E and II-X contract options are also available to STTR participants.

## Program Schedule

SBIR and STTR program year 2016 solicitation and award schedule is below.

| Date | Significant Event |
|---|---|
| Nov 2015 | FY 2016 SBIR and STTR Phase I Solicitation Opens |
| Feb 2016 | FY 2016 SBIR and STTR Phase 1 Solicitation Closes |
| Mar 2016 | FY 2017 Topics Requested from Mission Directorates and Centers |
| Apr 2016 | FY 2016 Phase I Awards Selected |
| Apr 2016 | FY 2016 SBIR Phase II Awards Selected (from prior Awards) |
| May 2016 | FY 2016 STTR Phase II Awards Selected (from prior Awards) |
| Aug 2016 | FY 2017 SBIR and STTR Phase I Final Topics and Subtopics Reviewed and Concurred on by Mission Directorates and Centers |
| Nov 2016 | FY 2017 SBIR and STTR Phase I Solicitation Open |
| Jan 2017 | FY 2017 SBIR and STTR Phase I Solicitation Closes |
| Mar 2017 | FY 2018 Topics Requested from Mission Directorates and Centers |
| Apr 2017 | FY 2017 Phase I Awards Selected |
| Apr 2017 | FY 2017 SBIR Phase II Awards Selected (from prior Awards) |
| May 2017 | FY 2017 STTR Phase II Awards Selected (from prior Awards) |
| Aug 2017 | FY 2018 SBIR and STTR Phase I Final Topics and Subtopics Reviewed and Concurred on by Mission Directorates and Centers |

# SBIR AND STTR

## Program Management & Commitments

| Program Element | Provider |
|---|---|
| SBIR and STTR | Provider: Various Small Businesses and their research partners<br>Lead Center: NASA HQ; Level 2: Ames Research Center (ARC)<br>Performing Center(s): All centers play a project management and implementing role.<br>Cost Share Partner(s): SBIR Phase II-E matches cost share funding with SBIR and STTR up to $125,000 of non-SBIR and non-STTR investment(s) from a NASA project, NASA contractor, or third party commercial investor to extend an existing Phase II project to perform additional research. SBIR Phase II-X matches, on a two for one basis, up to $250,000 of NASA program or project funding, thus enabling a maximum of $500,000 of SBIR/STTR award funds from the NASA SBIR/STTR Program. The total cumulative award for the Phase II contract plus the Phase II-X match is not expected to exceed $1,000,000 of SBIR/STTR funding. |

## Acquisition Strategy

SBIR and STTR program management work collaboratively with NASA Center Chief Technologists (for STTR) and a Mission Directorate Steering Council (for SBIR) during the SBIR and STTR acquisition process. This collaboration, from topic development through proposal review and ranking, supports final selection. Mission Directorates and NASA center program personnel interact with SBIR and STTR award winners to maximize alignment and implementation of the SBIR and STTR products into NASA's future missions and systems. Space Technology writes SBIR and STTR topics and subtopics to address NASA's core competencies and align with the Agency's Technology Roadmaps.

### MAJOR CONTRACTS/AWARDS

CRP awarded 17 CRP contracts for $5.4M in FY 2015 to further develop and commercialize technologies. These companies are listed below:

| Vendor | Location (of work performance) |
|---|---|
| Porifera | Hayward, California |
| Vista Photonics | Las Cruces, New Mexico |
| Techshot | Greenville, IN |
| Blue Canyon | Boulder, CO |
| MMA Design | Boulder, CO |
| Space Micro | San Diego, CA |
| Honeybee Robotics | Brooklyn, NY |

# SBIR AND STTR

| Vendor | Location (of work performance) |
|---|---|
| Bally Ribbon Mills | Bally, PA |
| Vanguard Space Technologies | San Diego, CA |
| Air Squared | Broomfield, CO |
| Deployable Space Systems, Inc. | Goleta, CA |
| Distant Focus Corporation | Champaign, IL |
| Nuvotronics, LLC | Radford, VA |
| TDA Research, Inc. | Golden, CO |
| ROCCOR, LLC | Louisville, CO |
| Busek Company Inc. | Natick, MA |
| Fibertek, Inc. | Herndon, VA |

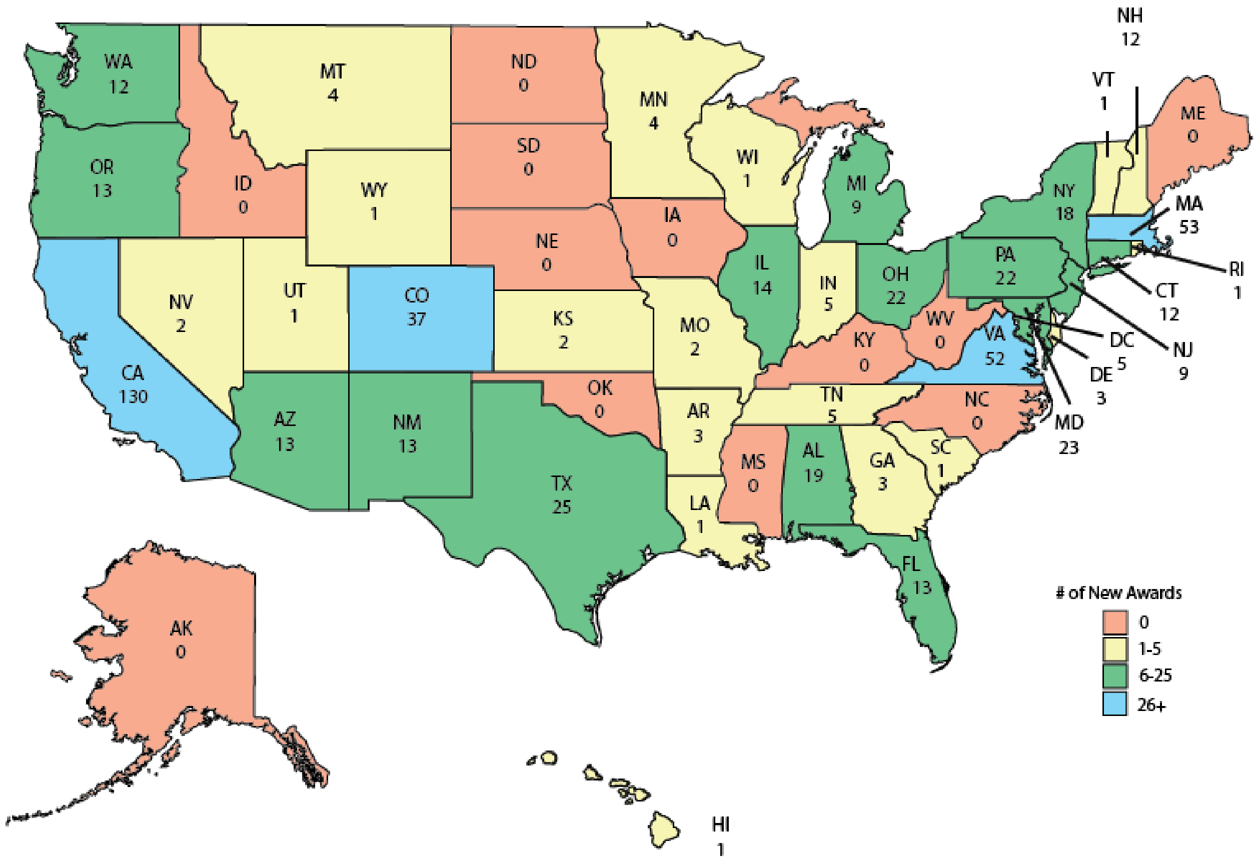
## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Perform-ance | National Academies | Ongoing | Assessment of the SBIR program. | TBD | Ongoing |
| Perform-ance | Government Accountability Office (GAO) | Ongoing | The GAO has been tasked to assess all SBIR and STTR programs for their performance in combating Waste, Fraud, and Abuse. | GAO found no concerns to address. | Ongoing |

## Historical Performance

The map below represents SBIR and STTR Phase I, Phase II, Phase II-E, and Select Awards, which target technologies highly desired by NASA Mission Directorates, made in FY 2015, represented by geographic location.

Fiscal Year 2015 SBIR/STTR Awards (Phase I, II, & II-E)



# SPACE TECHNOLOGY RESEARCH AND DEVELOPMENT

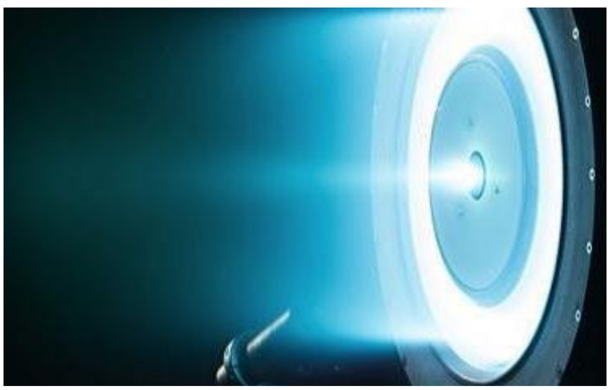
## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **378.3** | **--** | **579.4** | **456.2** | **469.3** | **482.7** | **496.6** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*



**Space Technology completed thruster performance acceptance and thermal characterization testing at NASA Glenn Research Center (GRC). This testing represents a key milestone toward understanding the performance parameters of the 12.5-kilowatt (kW) thruster unit and compatible power processing units for SEP.**

NASA invests in space technologies to enable or significantly advance relevant capabilities for NASA missions while also providing for a more capable aerospace sector. Through these efforts, NASA ensures the emergence of new ideas and the incorporation of advanced capabilities into its missions, while simultaneously contributing to the needs of other U.S. government agencies and the larger aerospace industry.

The Space Technology Research and Development (STRD) portfolio supports a range of technology maturation levels including early stage conceptual studies that focus on discovering new concepts and technologies, rapid competitive development and ground-based testing to determine feasibility, and flight demonstrations in relevant environments to complete the final step before mission use. By supporting projects at all TRLs, Space Technology creates a technology pipeline, starting with diverse early stage innovations, progressing along multiple paths to deliver mature, ready-to-use technologies that increase the Nation’s in-space capabilities. In the process of creating these new technologies, NASA supports research opportunities and inspires the next generation of inventors, scientists, and engineers.

Technology investments in robotics, automation, structures, materials, manufacturing, communications, and computing also have broad application within U.S. technology and aerospace industries. As a result, Space Technology represents NASA in the National Nanotechnology Initiative, the Advanced Manufacturing Partnership, the National Robotics Initiative, and the Materials Genome Initiative. These initiatives enable NASA to take advantage of and contribute knowledge toward common challenges across a network of government, academia, and industry experts. In addition, strategic investments supported within these initiatives bring new solutions to NASA and private industry through an expansion of the Nation’s technology base. By demonstrating new manufacturing techniques and developing new materials using nanotechnology, and materials genomics. NASA contributes to the growth of the Nation’s innovation economy. Space Technology conducts virtual workshops, creates technology infusion plans, and uses unfunded and funded Space Act Agreements to share expertise with industry and academia and improve the probability of infusion into the user community.

Technologies advanced within Space Technology Research and Development target key technology thrust areas both within and outside of NASA, including high-power SEP; life support and resource utilization; entry, descent, and landing; space robotic systems; optical communications; deep-space navigation; lightweight structures; and space observatories. Significant advances are required in these technologies to enable more capable science missions as well as human exploration missions that are both more affordable and reliable. In addition, the Agency looks to Space Technology to develop entirely new approaches to future missions. For example, STMD is rapidly advancing technologies to enable more capable small spacecraft, including nanosats, to conduct more affordable science missions and open up new opportunities for commercial space enterprises. Technology investments in propulsion, attitude determination and control, communications, power systems and autonomy can rapidly advance small spacecraft capabilities making them a more viable platform for a broader set of NASA missions and commercial applications. Space Technology is also investing in low size, weight, and power remote sensing instruments to enable science missions utilizing small spacecraft. This is one of many activities, funded by Space Technology, to develop pioneering technologies that will increase the Nation's ability to perform space science, improve operations in space, and enable future deep-space exploration missions.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Mandatory Budget Authority** | -- | -- | 136.1 | -- | -- | -- | -- |

STRD is supported in part by mandatory funding (see table). The mandatory investment includes $27.3 million for Game Changing Developments (GCD) and $108.8 million for TDMs.

## ACHIEVEMENTS IN FY 2015

- Continued breakthrough development of a three-dimensional layer-to-layer, woven thermal protection system, which has applications for extreme entry environments. Using a densely woven approach, the promising materials will be utilized on the Orion crew flight vehicle and support SMD for their potential application on future planetary science missions;
- Began development of the second-generation Mars Entry, Descent, and Landing Instrumentation (MEDLI) sensor suite for incorporation into the Mars 2020 mission heat shield. This instrument will provide critical data to improve the design of future EDL systems;
- Conducted a non-nuclear terrestrial demonstration of a power system to convert heat into energy to be used anywhere, regardless of available sunlight in partnership with the Department of Energy and small businesses (Sunpower, Inc. and Material Innovations, Inc.);
- Delivered two microfluidic-electrospray propulsion thruster designs that have the potential to transform small spacecraft propulsion. These thrusters, designed by Busek Company (Natick, MA), and the Massachusetts Institute of Technology (MIT), will each offer a highly reliable

alternative to reaction wheels for fine pointing capability on large satellites. These technologies will be further developed through propulsion pathfinder missions on small spacecraft platforms;

- Completed integration and functional testing of a rover prototype for a potential lunar mission with HEOMD. HEOMD is pursuing international and domestic partners to collaborate on this mission. Integrated the instrument payload and successfully conducted rover remote operations with ARC, Johnson Space Center (JSC), and KSC. The prototype rover was designed, fabricated, integrated, and tested in 9 months.
- Delivered carbon dioxide and humidity removal prototype system based on Rapid Cycle Amine (RCA) technology. The RCA technology is baselined for use in NASA's next-generation space suit and will undergo performance testing within an advanced Portable Life Support System (PLSS) under development by the HEOMD Advanced Exploration Systems (AES) program. This technology eliminates carbon dioxide removal as a duration-limiting subsystem and the humidity removal feature significantly reduces system complexity.
- The Advanced Space Power Systems project successfully completed testing of a 100W, regenerative fuel cell (RFC). This is the first demonstration of an RFC system with passive fluid management technologies to significantly improve system reliability while reducing mass, volume, and parasitic power, a loss occurring in a system when components draw power even though turned off.
- Initiated several new Centennial Challenges including the Cube Quest Challenge for deep space CubeSat exploration with a $5 million prize purse, an additive manufacturing challenge, and in partnership with National Science Foundation, a robotics automation challenge as a follow-on to the DARPA robotics challenge. The results of these challenges will enable teams to meet the objectives of designing, building and delivering flight-qualified, small satellites capable of advanced operations near and beyond the moon, developing architectural concepts that take advantage of 3D printing capabilities to imagine what habitats on Mars might look like, and demonstrating an autonomous robot that can navigate and collect samples;
- CIR completed 120 activities in basic research, applied research, and early stage technology development;
- The SEP project completed performance acceptance and thermal characterization tests that demonstrated full performance compatibility between thruster and Power Processing Units ;
- The LDSD project completed the development of two 30m ring sail parachute and all integration activities for Test Vehicle 3, and successfully executed Supersonic Flight Dynamic Test 2 from Pacific Missile Range Facility in Kauai in June 2015. Although the parachute did not survive full inflation, the ballute, and supersonic inflatable decelerator were successful and were able to achieve TRL 6-7. Better insight and understanding of the physics of supersonic parachute deployment and inflation was gained from this flight demonstration;
- GPIM completed propulsion system to spacecraft integration, satellite performance testing, and initiated environmental testing; and
- The DSAC project completed system integration, performance testing and initiated environmental testing.

### WORK IN PROGRESS IN FY 2016

- On November 19, 2015, NASA secured partnerships with 22 U.S. companies through the Announcement of Collaborative Opportunity and Tipping Point solicitations to advance the Agency's goals for robotic and human exploration of the solar system by shepherding the development of critical space technologies. The awards included nine fixed price contracts with at least 25 percent matching funds from a corporate or customer contribution. The awards will result in system-level demonstrations of robotic in-space manufacturing and assembly technology, gravitational measurements, methane sensing, and propulsion and attitude control systems for small spacecraft. Also developed were non-reimbursable partnerships that provide access to NASA expertise in areas such as suborbital and nano-launch capability development, thermal protection systems, green propellant thruster qualification, and Liquid Propellant Rocket Engine Development;

- To enable scientific discovery, Space Technology will complete software development and testing of Station Explorer X-ray Timing and Navigation Technology (SEXTANT) at the Goddard Space Flight Center (GSFC), which will evaluate real-time X-Ray data from known regular pulsars to demonstrate more precise deep space navigation. This ISS demonstration will use pulsars for navigation similar to the way GPS functions on the Earth today;
- With application to both commercial and NASA operations, Space Technology will complete Preliminary CDR and KDP-C for the LCRD mission. Set to fly as a hosted payload, this technology demonstration project will demonstrate an order of magnitude leap in communications capability that could be used for future Tracking and Data Relay Satellite (TDRS) satellites, other government agencies as well as commercial space communications providers;
- With Mezzo Technologies located in Baton Rouge, LA, Space Technology is developing two phase-change-material heat exchangers: One uses wax and the other uses water to store thermal energy. The microgravity performance of these heat exchangers was assessed on the ground. The wax-based heat exchanger is ready for delivery to the International Space Station for in-space demonstration before infusion with Orion's thermal control system. The infusion of this technology will allow the vehicle to successfully operate throughout the duration of a lunar orbit;
- In early CY 2016, Space Technology will conduct four flight demonstrations: CubeSat Proximity Operations Demonstration (CPOD) for rendezvous and docking; Integrated Solar Array and Reflect Antenna (ISARA) for enhanced radio communications; Optical Communications and Sensor Demonstration (OCSC) focused on laser communications and formation flight; and Network & Operation Demonstration Satellite (Nodes) to demonstrate multi-point science measurements with very low cost satellites;
- CIF competitively awarded 114 new research and development activities for FY 2016;
- In FY 2016, in Flight Opportunities, NASA plans to make multiple awards to emerging commercial space companies in partnership with NASA centers for maturing and validating technologies needed for air-launched liquid rockets, dedicated CubeSat launch vehicle, nanosat launch vehicle booster main engine, and upper stage engine;
- The SEP project, as part of the ARRM Project, will complete the System Requirements Review (SRR) objective and the KDP-B life cycle review currently scheduled for Quarter four, FY 2016, and award the contract for the major technology components of the electric propulsion system for ARRM;
- Space Technology will complete environmental and performance testing for GPIM and deliver the spacecraft for launch as a secondary payload on a Falcon 9 Heavy launch vehicle no earlier than FY 2017 Quarter Two;
- Space Technology will complete integration and test of the DSAC flight systems, deliver the system to the spacecraft contractor for final integration onto the spacecraft as hosted payload, and launch no earlier than FY 2017 Quarter Two; and
- Space Technology will complete pre-formulation activities to refine the project requirements, budget and launch readiness date for Restore-L, the In-Space Robotic Servicing mission capable

of servicing a U.S. government satellite in low Earth orbit. MCR and KDP A will be completed in FY 2016.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

- Space Technology will award contracts for the development of high performance spaceflight computer processors that will allow for flexible operations, lower power computers for space operations with 75x-improved performance over the state of the art RAD750;
- Award the second round of public private partnership through the Tipping Point solicitation planned for release in FY 2016;
- Space Technology, in conjunction with HEOMD and SMD, will conduct a CDR for the Mars Oxygen ISRU Experiment payload on the Mars 2020 mission. The payload will demonstrate the in situ production of oxygen on Mars. This MIT-led in situ resource utilization demonstration selected using the Mars 2020 Instrument AO will produce oxygen with 99.6 percent purity over the course of at least 15 operational cycles;
- Space Technology will continue a steady cadence of new Centennial Challenges and early stage grants to engage academia, industry, entrepreneurs, and innovators in NASA's technology needs;
- In FY 2017, the Flight Opportunities Program will continue to explore partnerships to spur the development of nano-launch orbital capabilities development to spur development of small spacecraft launch systems. The aim of the effort is to enable emerging companies by sharing NASA expertise and relevant technologies to provide the Nation with frequent, reliable, and cost effective access to space for small payloads;
- Space Technology will provide technology development grants and academic funding support to more than 200 students and early career faculty through STRG and NIAC;
- Space Technology will initiate DSOC as a technology demonstration mission to provide high bandwidth communications for future deep space exploration of the solar system;
- The SEP project will support ARRM Project milestones that will be determined at KDP-B currently scheduled for Quarter four, FY 2016.
- Restore-L will continue formulation activities to support a technology demonstration mission capable of servicing a U.S. government satellite in low Earth orbit. STMD, partnering with HEOMD and SMD, will establish requirements for the Restore-L mission, leading to the start of Phase B before the end of FY 2017.

# Program Elements

## EARLY STAGE PORTFOLIO

Basic research, applied research, and early technology development seed and develop the innovations that enable transformative future capabilities. This process is nonlinear and takes time. It is not always clear which efforts will result in breakthroughs, effective improvements, or exciting new approaches. This is why a balance of early stage, mid-TRL, and technology demonstration investments is critical for a healthy technology development portfolio

Space Technology invests in early stage space technology research and development sourced from academia, industry, entrepreneurs and from the NASA workforce to bring pioneering approaches to the

Agency's difficult and far-reaching exploration challenges. As of FY 2016 first quarter, there are approximately 400 Early Stage activities spanning all technology areas (14 NASA space technology roadmap areas plus Aeronautics) with over 70 percent focused on the eight Space Technology thrust areas. Roughly 70 percent of the Early Stage Portfolio supports Science, 60 percent supports Exploration, and 10 percent supports Aeronautics. For example, improved materials could have downstream applications for diverse missions. Through a steady cadence of competitive solicitations, Space Technology continuously solicits and develops new and innovative high-risk/high-payoff technologies. Early Stage studies cultivate new ideas and alternative approaches, leveraging the technical capabilities of the experts across the nation to fuel economic growth. Technologies are often developed with support and coordination between NASA and various external partners. Space Technology's Early Stage Programs employ various approaches, to best engage technical experts at universities, companies, independent labs, NASA centers, and other government agencies: As an example of the progress in the early-stage portfolio, Daniel Szafir from the University of Wisconsin–Madison has developed a novel motion control mechanism for free-flying robots that can provide assistance to human work partners, to more effectively communicate their intentions to collaborators working in close proximity. This research has generated new methods for flying robots to signal flight directionality, increasing perceptions of robot safety and usability.

STRG annually conducts a series of competitive solicitations targeting high-priority technology areas that challenge the entire spectrum of academic researchers, from graduate students to early career and senior faculty members making science, space travel, and exploration more effective, affordable, and sustainable. These grants harness the unique environment that resides within our nation's universities to solve space technology's most difficult long-term challenges. In the process, Space Technology fortifies the close collaborations between U.S. universities and NASA. In FY 2015, Space Technology awarded 54 fellowships, 8 Early Career Faculty awards, and 11 Early Stage Innovations awards that resulted from the 2014 Early Stage Innovation solicitation. Early in FY 2016, Space Technology Research Grants selected 15 Early Stage Innovations efforts that resulted from the solicitation for proposals in FY 2015. The 2015 Early Career Faculty and Early Stage Innovations competitive opportunities featured 11 topics from 8 of the technology area roadmaps. Space Technology Research Grants has approximately 250 active fellowship, Early Career Faculty, and Early Stage Innovations awards; to date, Space Technology Research Grants has made 357 grant awards to 95 different U.S. universities in 42 states and one U.S. territory

NIAC executes annual solicitations seeking exciting, unexplored, technically credible new concepts that could one day "change the possible" in space and aeronautics. NIAC efforts improve the Nation's leadership in key research areas, enable far-term capabilities, and spawn disruptive innovations that make aeronautics, science, and space exploration more effective, affordable, and sustainable. NIAC annually issues both Phase I and continuation Phase II solicitations. These opportunities are open to NASA centers, other government agencies, universities, industry, and individual entrepreneurs. In 2015, NIAC made 15 Phase I and 7 Phase II awards across industry, academia, and NASA centers, while completing 12 Phase I and 6 Phase II studies. 2013 NIAC Fellow Dr. Chris Walker from the University of Arizona achieved a monumental research success for his research in creating a pressurized balloon mirror inside of a weather balloon to do astrophysics above 99 percent of the atmosphere without the cost of a spacecraft. This project has received multiple follow-on grants and contracts from NASA and the Department of Defense. Additionally, Dr. Joel Sercel, a former Caltech professor and Jet Propulsion Laboratory (JPL) employee, started his own company to apply to NIAC and other government agencies to explore his unique concept of mining asteroids for in-space propellant manufacturing.

# SPACE TECHNOLOGY RESEARCH AND DEVELOPMENT

CIF sparks the development of technology to transform future missions and advance the Nation's capabilities by stimulating aerospace creativity and grassroots innovation at all ten NASA centers through providing seed funds to selected projects and activities. CIF projects are competitively selected to explore alternative approaches or develop enhanced capabilities. They are solicited to directly address NASA strategic goals, progress along technology roadmaps, and/or address significant national needs. Partnerships with academia, private industry, individual innovators, as well as other NASA centers and Government agencies are highly encouraged. Space Technology at NASA HQ reviews finalizes all Center recommended selections to ensure a coordinated agency-side portfolio. . The benefits over time of early stage work can be seen through the example of 3D-woven thermal protection system. This development began as a CIF project in 2010 at the ARC (in partnership with Bally Ribbon Mills). In March 2015, woven thermal protection system compression pads passed Mission Infusion Review for inclusion on the Exploration Mission (EM)-2 Orion Test Flight.

Space Technology continues to enhance its involvement with academia and NASA centers to access unique ideas with breakthrough potential. In FY 2016 and FY 2017 solicitations, NASA will place an emphasis on foundational engineering science, targeting collaboration with the fundamental research community in fields such as synthetic biology and computational materials. It is expected that development of these concepts can open up new space engineering and science capabilities. Space Technology plans to establish one or more university based virtual institutes for sustained, coordinated research in key areas through a competitive solicitation in FY 2017. Development of virtual institutes help foster deeper collaboration between NASA, academia, and possibly industry to more effectively address common engineering research goals.

## GAME CHANGING DEVELOPMENT

Within GCD, NASA focuses on rapidly advancing disruptive space technologies from concept to demonstration, maturing transformational technologies across the critical gap between early stage research and flight demonstration. Technologies are primarily selected through competitive solicitations emphasizing capabilities most likely to be infused in to the known user community. Space Technology favors technology investments that offer direct partnerships and co-funding from NASA, industry, and/or other government agencies, to advance specific technologies needed by those customers. For example, key technology developments will address long-term challenges identified for outer planetary science missions by SMD, such as DSOC, advanced radiation tolerant spaceflight computing and woven Thermal Protection System materials. In partnership with the SMD, Space Technology has incentivized technology development and demonstration through the recently released Discovery 2014 solicitation. In addition, Space Technology partners with HEOMD to address challenges for human missions to Mars, such as converting carbon dioxide from the Mars atmosphere to oxygen and the development of high capacity batteries for next generation space suits. GCD also partners with other government agencies to explore solutions to common challenges in areas such as robotics, manufacturing, and materials. GCD makes fixed duration investments typically categorized within the investment areas described below.

### Landing Accurately: Advanced Entry Descent and Landing (AEDL)

In order for NASA to land more mass, more accurately on planetary bodies, the Agency must develop more capable entry, descent, and landing systems and materials. This includes the development of new aeroshell concepts and thermal protection system materials for Orion and future exploration vehicles. Space Technology designs, analyzes, and tests technologies, materials, and aeroshell architectures required for future planetary entry missions. Much of the work in this theme involves developing efficient ways to reduce spacecraft re-entry speed while providing protection from extreme frictional heating. One such remarkable breakthrough is the weaving of quartz yarns with resin transfer molding to develop a robust multifunctional material architecture capable of meeting both structural and thermal performance needs for a variety of NASA missions. Six full-scale 3D-woven TPS billets, developed by small business partners Bally Ribbon Mills and San Diego Composites, were delivered to Orion for eventual integration into flight vehicle for as the interface between the crew and service modules.

Exploration, Science, and Space Technology are partnering to develop the second-generation MEDLI sensor suite for incorporation into the Mars 2020 mission heat shield. This effort builds on the success of Curiosity's MEDLI instrumentation, and will further improve our understanding of entry system performance by acquiring flight data from an actual Mar's mission. Additional heat shield measurement locations, inclusion of supersonic aerodynamics, and backshell aerothermal and pressure measurements will inform NASA designs for future exploration missions.

To better understand the utility of supersonic retrorocket propulsion under Mars entry conditions, Space Technology will continue to evaluate flight data from SpaceX Falcon 9 first stage landing demonstrations. The Falcon 9 is using supersonic retro-propulsion (SRP) to conduct precision landing of the first stage, allowing SpaceX to reuse the stage and to validate the capability for potential future Mars landings. Space Technology also conducts advanced analytics and modeling for hypersonic flight including radiation, aerothermodynamics, and material thermal response analyses. This improved modeling capability will result in lower mass entry systems due to a better understanding of the thermal protection system thickness margins.

### Access and Travel through Space: Future Propulsion and Energy Systems (FPES)

Space technology personnel will complete integrated system tests of a small electric propulsion thruster using iodine propellant at the Marshall Space Flight Center (MSFC). The use of solid iodine as a propellant is beneficial because it significantly reduces the required storage volume while simultaneously eliminating the need for the expensive, high-pressure tanks required to store gaseous propellants. In addition, the program initiating a nuclear thermal propulsion fuel development study, which may lead to fuel element demonstrations in FY 2017.

Space Technology is also making critical advancements in power generation, storage, and transmission technologies with a focus on outer planetary exploration. This includes development of solar array technology that can generate energy in extreme environments including low light intensity and low temperature.

Space Technology also supports advanced in-space power storage by investigating and maturing advanced alternate chemistry and lithium-ion batteries with a goal to safely quadruple the specific energy of the best commercially available rechargeable batteries. Four Phase I SBIR battery designs selected in late FY 2014 were evaluated in the spring of 2015. Two of these designs were down selected for further development, and a single battery prototype will be delivered to Exploration for validation in FY 2017. Space Technology will continue to mature fuel cell technology for space application.

### Enabling Scientific Discovery: Revolutionary Robotics and Autonomous Systems (RRAS)

Robotics and autonomous systems are critical when exploring or operating in an extreme environment, on Earth or in space (especially for outer planets exploration). Human Robotics Systems technology also supports the Agency's role in the National Robotics Initiative by issuing grants for robotics technologies that benefit space exploration and also support manufacturers, businesses and other entities. Specific technology efforts include the development of:

- Pop Up Flat Folding Exploration Robots (PUFFER): This initiative is designed to develop folding, impact absorbing robots to enable new science by providing future missions with low-cost access to new terrains. This project will complete its final field demonstration in 2017;
- Astrobee, a new freeflyer robot for use inside ISS as a follow-on to SPHERES. This robotic system will improve the crew's efficiency by autonomously performing the more mundane and monotonous tasks such as inventory management and air quality assessments. In addition, with its open source software platform, it will continue to be available for use by universities and for telerobotics challenges on ISS; and
- Humanoid robots through collaboration with Centennial Challenges and the NSF. NASA will leverage the DARPA robotics challenge as an on ramp to initiate a NASA robotic challenge and to form partnerships with private and university organizations that show potential to dramatically improve NASA's future robotic capabilities. Space Technology is maturing the Robonaut software to improve the robot's efficiency and autonomy further freeing up the crew's valuable time.

### Enabling Industry: Lightweight Materials and Advanced Manufacturing (LMAM)

Space Technology supports innovation in low-cost manufacturing processes such as additive and digital manufacturing. NASA looks for opportunities to improve the manufacturing technologies, processes, and products prevalent in the aerospace industry. These collective efforts support NASA's role as part of the President's Advanced Manufacturing Partnership, including the Agency's role in the National Network for Manufacturing Innovation, and contribute to NASA's participation and interface with the National Nanotechnology Initiative and the Materials Genome Initiative. NASA's participation has enabled the Agency to be part of a network focused on cutting edge manufacturing methods and technologies. Included within this portfolio are the following:

- Using cutting-edge materials and emerging capabilities to design, develop, and hot fire test an additively manufactured upper stage class rocket engine combustion chamber and nozzle;
- Exploring nanotechnology research and applications for aeronautics and space, with a focus on reducing vehicle mass and improving reliability through the development of carbon nanotube-based materials. This includes investments in nano-manufacturing through the development of carbon nanotube structural materials, and lightweight carbon nanotube/aerogel wires, and cables; and
- Developing and manufacturing ultra-lightweight materials for aerospace vehicles to demonstrate lower-mass alternatives to honeycomb or foam cores currently used in composite sandwich structures. GCD awarded 3 contracts (HRL Laboratories, Orbital ATK Space Systems, and Dynetics) to develop and manufacture ultra-lightweight materials. As a follow-on to these awards, STMD will downselect to the most promising composite core technology for large-scale development and demonstration.

### Enabling Scientific Discovery: Affordable Destination Systems and Instruments (ADSI)

Space Technology will fundamentally transform spacecraft systems through investment in high payoff technologies that increase communication data rate, increase the sensitivity of scientific instruments and sensors, advance navigation and flight avionics, advance thermal control systems in-situ resource utilization technologies, advance closed-loop life support systems, and develop capabilities to mitigate space radiation. Included within this portfolio are:

- Working with both Space Communications and Navigation (SCaN) and Planetary Science, GCD is developing technologies that enable deep space optical communication to provide 100 times increase in data rates available on NASA's exploration missions. By late FY 2016, the GCD project will reach TRL-6 on these technologies and transition to the TDM program to fully demonstrate a high bandwidth flight laser communication terminal that will be ready to infuse as GFE for the SMD Discovery mission;
- With the Air Force Research Laboratory, NASA will develop a high performance space flight computing system. This development effort will lead to vastly improved in-space computing performance, energy management, and increased radiation fault tolerance. The new radiation tolerant microprocessor will offer a 100 times improvement in performance relative to the current state of the art RAD750 processor while requiring the same power;
- With the NASA Space Radiation Laboratory, GCD will design and build radiation detector stands and targets to support a four-year project to test various materials (aluminum, polyethylene, combination). This effort will result in the acquisition of data that will inform deep space habitat construction;
- With Exploration, Space Technology selected four partners to develop technologies that will increase the oxygen recovery rate aboard human spacecraft to at least 75 percent while achieving high reliability. These systems are critical when oxygen resupply from Earth is not available. Future maturation of these technologies may use the ISS National Laboratory as a proving ground to retire risk and gain experience with capabilities needed for deep-space exploration; and
- With Science, Space Technology advanced coronagraph technologies for the WFIRST/AFTA mission to dramatically improve our ability to directly observe exoplanets, and interrogate the atmospheric properties of these distant worlds allowing humanity to discover habitable planets within our galaxy for the first time.

## TECHNOLOGY DEMONSTRATION MISSIONS

To bridge the gap between early development and mission utilization, TDM matures system-level space technologies that can benefit multiple NASA missions, other government agencies, and aerospace industry stakeholders by demonstrating prototypes and demonstration units in relevant environments. To remain affordable, flight demonstrations of technologies that have passed feasibility ground testing are supported primarily through hosted payloads, rideshares and secondary payloads. The current TDM portfolio is described below:

### Enabling New Commercial Applications: Restore-L– Satellite Servicing

Working with GSFC, Space Technology in partnership with HEOMD and SMD will demonstrate robotic servicing of satellite through the Restore-L mission. Restore-L is a full-scale technology demonstration mission to advance technologies that enable on-orbit satellite life extension. Technology areas include dexterous robotics, autonomous rendezvous and docking systems, propellant transfer systems, and sophisticated robotic tools with the ultimate goal of servicing a U.S. government satellite in low Earth orbit. Building on the Robotic Refueling Mission technology demonstrations on ISS, Restore-L will advance servicing technologies to operational status and partner with domestic private enterprise to commercialize the results, establishing a new U.S. industry.

# SPACE TECHNOLOGY RESEARCH AND DEVELOPMENT

### Enabling Scientific Discovery: Deep Space Optical Communication (DSOC)

Partnering with the JPL, Space Technology is working to develop key technologies for the implementation of a deep space optical transceiver and ground receiver that will provide greater than 10 times the data rate of a state of the art deep space RF system (Ka-band). This will enable future advanced instruments, live high definition video, tele-presence, and deep-space human exploration of the solar system. DSOC technologies are considered essential for future human missions to Mars and have a wide range of applicable planetary science missions including those to Mars and Jovian systems.

In collaboration with SMD and HEOMD, the STMD GCD DSOC project is working to mature and reduce significant risks on technologies such as a low mass spacecraft disturbance isolation assembly, a flight qualified photon counting detector array, a high efficiency flight laser amplifier, and a high efficiency photon counting detector array for the ground-based receiver. By late FY 2016, the GCD project will reach TRL-6 on these technologies and transition to the TDM program to fully demonstrate a high bandwidth flight laser communication terminal that will be ready to infuse as GFE for the SMD Discovery mission. Currently, three of the five Discovery proposals included DSOC and a fourth proposal is currently considering inclusion for a notional launch date in CY 2021.

### Improving Deep Space Travel: Deep Space Atomic Clock (DSAC)

In collaboration with the JPL, Space Technology is working to validate a miniaturized, mercury-ion, atomic clock that is 100 times more accurate than today's state of the art space clocks used for spacecraft navigation systems. The DSAC project will demonstrate ultra-precision timing in space and its benefits for one-way radio-based navigation in late FY 2016. If successful, it will free precious deep space communications bandwidth to perform greater scientific data return, instead of receiving and transmitting navigation updates. The enhanced navigation and opening of communications bandwidth permitted by the new clock will dramatically improve the science return capabilities of future Discovery and New Frontiers missions, particularly for outer planetary missions. The accurate timing and navigation provided by the clock will also dramatically improve gravitational measurements planned for a future Europa (and other icy moons) mission to characterize the under ice liquid water oceans. Precision timing and navigation provided by the new clock will also have the potential to improve the Nation's next generation GPS system. The demonstration is planned for launch via rideshare on a SpaceX Falcon Heavy 9 (STP-2) as a hosted payload on the Surrey Orbital Test Bed by no earlier than late FY 2016, and is funded in a partnership with SCaN.

### Advancing In Space Propulsion: Green Propellant Infusion Mission (GPIM)

Space Technology and partners Ball Aerospace and Aerojet Rocketdyne along with the Department of Defense designed, built, tested, and are launching a dedicated spacecraft to demonstrate non-toxic propellant propulsion with the goal to provide an alternate to hydrazine propellant applicable to a small to medium-sized spacecraft. Hydrazine used extensively since the 1960s for space systems, is a reliable and effective storable monopropellant, but requires complicated transportation, handling, and ground/flight operations because it is highly corrosive and highly toxic. Use of hydrazine also often requires extensive site clean-up and environmental remediation at the end of missions and programs due to the material's toxic properties. Spacecraft developers have actively sought safer alternatives to hydrazine propellant (in-space storable mono propellants). Higher performing and safer green propellant alternatives are at a tipping point. Once demonstrated within the context of an in-space application, rapid incorporation could occur into a variety of spacecraft. NASA selected AF-M315E as an innovative, low-toxicity monopropellant alternative with improved performance over hydrazine. The AF-M315E propulsion system is expected to improve overall vehicle performance and processing efficiency while decreasing operational costs by reducing health and environmental hazards. The green propellant formula, thrusters, and related systems will perform a series of in-space demonstration tests. NASA has secured a rideshare opportunity for a no earlier than FY 2016 technology demonstration via the STP-2 launch of a SpaceX Falcon 9 Heavy. In addition, Space Technology will continue to work with Aerojet Rocketdyne to revise the one Newton thruster design to implement design improvements that were uncovered during this project to better enable infusion potential following the in-space demonstration.

### Enabling New Commercial Applications and Deep Space Exploration: Solar Electric Propulsion (SEP)

Space Technology, working with GRC and ARRM, will continue the development of SEP with higher power, longer-life thrusters, and power processing units. The use of electric thrusters on commercial satellites continues to increase and recent NASA advancements in deployable solar array structures, with half of the mass and one-third of the packaging volume compared to the best current arrays, are already being incorporated into commercial satellite product lines. Hall-Effect thrusters designed to operate at over 12 kilowatts and with magnetic shielding to permit years of continuous operations without degradation are being competitively procured by NASA. A three-year contract for engineering and flight unit delivery of thrusters and power processing units will be awarded in spring 2016. A test unit for such a thruster was developed by the GRC and successfully completed vacuum chamber testing throughout its full performance envelop during 2015. The complete SEP system will be demonstrated as part of the ARRM with other potential demonstration missions also under consideration.

Once proven, high-powered SEP will enable more efficient orbit transfer for satellites and accommodate the increasing power demands for government and commercial satellites. Furthermore, SEP can efficiently propel NASA’s future robotic science and human exploration missions beyond the Earth and into deep space.

### Enabling Industry and Scientific Discovery: Laser Communications Relay Demonstration (LCRD)

The goal of the LCRD project is to demonstrate bi-directional optical communications relay services between geosynchronous orbit and Earth. The outcome of this demonstration will prove optical communications technology in an operational setting, providing data rates up to 100-times faster than today’s radio frequency based communication systems. The demonstration will measure and characterize the system performance over a variety of conditions, develop operational procedures, assess applicability for future missions, and provide an on orbit capability for test and demonstration of standards for optical relay communications. This will have major implications for NASA, other agencies, and the U.S. satellite manufacturers and operators. In FY 2014, Space Technology released a Request for Information (RFI) to gauge industry interest in this technology and ensure that the planned design specifications will permit utilization into the commercial communications industry. The RFI responses indicated that this technology has great value to industry in responding to the rising demand for bandwidth. After the in-space technology demonstration becomes operational, NASA will provide access to the system for the communications industry to test the capabilities for their needs. On completion, NASA will transfer laser communication technology to industry for future missions.

# SPACE TECHNOLOGY RESEARCH AND DEVELOPMENT

### Landing Accurately: Low Density Supersonic Decelerators (LDSD)

Space Technology, working with JPL, has the goal of developing and demonstrating new EDL technologies capable of increasing the landed mass and landing accuracy over current baseline systems. NASA has utilized Viking era parachutes for decades to perform supersonic deceleration for Mars science landers. These descent parachutes along with the rest of Mars EDL systems have reached the upper limit of their capacity (approximately one metric ton). Space Technology developed and tested a variety of supersonic decelerator systems to support future larger Mars missions. The project designed, developed, and tested a supersonic ring-sail parachute as well as a pair of supersonic inflatable aerodynamic decelerator systems. The parachute and inflatable decelerators were put through a series of tests utilizing wind tunnels, balloon drops, rocket sleds, and rocket-powered, high-altitude (180,000 feet) supersonic (Mach 2 to 4) flight demonstrations. This effort is in partnership with NASA's Planetary Science Division. Due to a failure of the supersonic parachute to deploy properly during an FY 2015 test, the LDSD project held a series of technical and programmatic boards to study the failure and the project is in the process of determining the next steps in the advancement of EDL technologies. No funds are requested for LDSD in FY 2017.

### Enabling Industry: Composites for Exploration Upper Stages

Reducing the mass of launch vehicles will allow for greater payload capacity. Existing human space flight vehicles do not utilize composites for primary structures since validation of the critical technologies has not occurred at scale and in a relevant environment. Building on the success of the Composite Cryotank Technologies & Demonstration and on advanced composites integrated modeling conducted by Space Technology, the Composite Exploration Upper Stage project, working with the MSFC, focused on developing and demonstrating additional composite for application on launch vehicles with the goal of proving out certification of large scale composite structures on space launch vehicles that have broad applicability across the aerospace industry. The objective is to provide validated alternative structural materials for designers to use in future versions of commercial and government launch vehicles. This effort was to develop, design, and validate manufacturing processes for using composites that can be applied to other large space structures and science platforms developed across the aerospace industry. The project is a cooperative effort between Space Technology and Exploration, involving multiple NASA centers. No funds are requested for Composites for Exploration Upper Stages in FY 2017. The Composite Exploration Upper Stages project will be discontinued due to budget constraints and NASA technology investment priorities.

### Access and Travel through Space: Evolvable Cryogenics (eCryo)

Managing cryogenic fluids and minimizing boil-off of cryogenic propellants on long duration missions is a critical capability needed to enable high-performance in-space propulsion stages, a key component of future human spaceflight architectures. Advancements in cryogenic fluid management will address challenges experienced by NASA and commercial launch providers by demonstrating the capability of in-space long-term storage, transfer, and mass gauging of cryogenic propellants (i.e. liquid oxygen and liquid hydrogen). With the eCryo project, Space Technology will conduct a series of ground demonstrations at MSFC and GRC to validate the performance of propellant storage tanks designed for long-term storage. In addition to managing the propellant boil-off by validating the effectiveness of advanced multi-layer insulation, the team will look to reduce ancillary system weights mass and complexity. The project will also investigate the utilization of remaining boil-off gases to replace existing pressurization and attitude control systems and to provide electrical power for the Space Launch System (SLS) Exploration Upper Stage. In addition, the team will develop new cryogenic monitoring instrumentation and analytical models to assist in determining cryogenic health during in space operations. For NASA, these technologies enable beyond low Earth orbit exploration missions, while industry will likely infuse the technologies on next generation launch vehicles—particularly upper stages—making them more efficient and capable. By taking an incremental ground test approach, Space Technology will prioritize technologies needed by SLS upper stage development and the long-term needs of the aerospace industry as a whole. The project will build on the knowledge gained from previous investments and utilize existing Agency assets and test facilities capable of maturing cryogenic propellant technologies.

### Enabling Industry: Robotic In-Space Manufacturing and Assembly of Spacecraft and Space Structures

Space Technology will develop and demonstrate technologies required to assemble, aggregate, and/or manufacture large and/or complex systems in space utilizing robotics technology. Presently, launch-shroud size, lift capacity, and launch loads/environments are factors that limit the size and capabilities of systems pre-assembled on the ground and deployed using a single launch. The following competitively awarded proposals were selected in November 2015:

- Public-Private Partnership for Robotic In-Space Manufacturing and Assembly of Spacecraft and Space Structures—Orbital ATK of Dulles, Virginia;
- Versatile In-Space Robotic Precision Manufacturing and Assembly System—Made in Space, Inc. of Moffett Field, California; and
- Dragonfly: On-Orbit Robotic Installation and Reconfiguration of Large Solid RF Reflectors—Space Systems Loral of Palo Alto, California.

With advances in ultra-lightweight materials, robotics, and autonomy, in space manufacturing, assembly, and aggregation concepts are now at a tipping point. This disruptive capability could transform the traditional spacecraft-manufacturing model by enabling in-space creation of large spacecraft systems. No longer will developing, building, and qualifying a spacecraft focus so heavily on an integrated system that must survive launch loads and environments. These crosscutting technologies could also greatly reduce cost while increasing capabilities for both NASA and commercial space applications. For example, the in-space assembly or manufacturing of large RF or optical reflectors, solar arrays, or entire spacecraft could transform the commercial communications satellite market as well as offer benefits to future NASA missions.

## SMALL SPACECRAFT TECHNOLOGY

Small Spacecraft Technology develops and demonstrates technologies to enhance and enable new small spacecraft capabilities. NASA invests in small spacecraft to provide a low-cost platform for rapid in-space demonstration of new technologies and innovations that are applicable across the space sector. Small Spacecraft are most often delivered to space using a rideshare approach, where the spacecraft uses launch vehicle volume and lift capability that would otherwise go unused by a primary payload. NASA will share the results of the program’s technology developments and demonstrations with the national space community to provide opportunities for infusion into ongoing or planned missions. Small Spacecraft Technology is supporting the following development projects:

- The Pathfinder Technology Demonstrator series of missions is being formulated to conduct flight demonstrations beginning in 2017. The overall Demonstrator objective is to expand capabilities in propulsion and other technologies for small spacecraft. This project will demonstrate miniaturized electrospray propulsion systems, electric thrusters, and other innovative propulsion systems. Pathfinder will fly technologies derived from the Tipping Point solicitation, SBIR projects, and other sources, using 6U CubeSat buses procured from industry;

- A flight demonstration of innovative electric propulsion using iodine propellant with a 200W Hall thruster is under development by a team at MSFC, working toward a flight in 2017; and
- The Smallsat Technology Partnerships, involving collaboration between universities and NASA centers, continue with completion of eleven projects selected in 2014. Two of those projects have been awarded launch opportunities by NASA. Eight new two-year projects were selected in 2015 and future solicitations will occur on an annual basis.
- NASA will participate in the Small Payload Rideshare Working Group to engage with small spacecraft stakeholders on small spacecraft launch standards.

## CENTENNIAL CHALLENGES

Centennial Challenges offers incentive prizes to generate revolutionary solutions aimed to support future NASA missions to Mars and beyond. The program seeks innovations from diverse and non-traditional sources, directly engaging the public in the process of developing advanced technology. Competitors are not provided government funding for their development; awards are only made to successful teams when the challenges are met. The NASA Centennial Challenges partners with organizations inside and/or outside of NASA to manage challenges with the goal of maximizing return of investment to the agency.

The following challenges were performed in FY 2015:

- The fourth year of the Sample Return Robot (SRR) Challenge was hosted by Worcester Polytechnic Institute. The challenge purpose is to demonstrate robots that can locate and retrieve geologic samples from a wide and varied terrain without human control or use of terrestrial navigation aids. Fourteen teams participated in the Level 1 competition; no team qualified to move into the next level of the challenge. Two teams, which previously qualified to participate in Level 2, competed in the 2015 event. The West Virginia University team captured and returned two Level 2 samples and received a $100,000 award. The total prize purse for this challenge is $1.5M;
- Space Technology conducted the first of four Ground Tournaments for the Cube Quest Challenge. The purpose of the challenge is to design, build, and launch flight-qualified, small satellites capable of advanced operations near and beyond the moon, to demonstrate communications and propulsion technologies. ARC is working with San Jose State University to manage this challenge. Thirteen teams participated in Ground Tournament-1 (GT-1); Ground Tournaments 2 and 3 will be executed in FY 2016 and the final ground tournament in FY 2017. Five teams met GT-1 requirements and each team won $20,000. The top three teams that win the final ground tournament will have the opportunity to become secondary payloads on the first integrated flight of NASA’s Orion spacecraft and SLS rocket. The total prize purse for this challenge is $5.5M;
- A level 1 design challenge of the 3D Printed Habitat Challenge was executed in FY 2015. The purpose of the Habitat challenge is to advance additive construction technology to create sustainable housing on Earth and beyond. Over 165 entries were received for the Design Competition, of which 94 met the minimum requirements. The top 30 finalists competed for the top three places at the World Maker Faire in New York. The first-place winner, Team Space

# SPACE TECHNOLOGY RESEARCH AND DEVELOPMENT

Exploration Architecture and Clouds Architecture Office, was awarded $25,000. The second-place winner, Team Gamma (Foster + Partners), was awarded $15,000. The third-place winner, EAS European Astronaut Centre, was not awarded prize money because the team was not from the United States. The Level 2 of the Challenge will be executed in FY 2016 and FY 2017. The total prize purse for this challenge is $2.25M; and

- The second year of the Mars Ascent Vehicle Challenge opened for registration in late FY 2015. Teams are challenged to develop an autonomous robotic system that can load a sample into a rocket, launch to a predetermined altitude of 5,280 feet, and safely return the sample container to the Earth’s surface. A team from MSFC is managing the challenge. Fifteen teams participated in the 2015 competition (first year). The winners of the competition were North Carolina State Univ. (1st Place, $25,000) and Tarleton State Univ. (2nd Place, $15,000). The total prize purse for this challenge is $50K.

Future Centennial Challenges will address:

- NASA’s efforts in robotics for human exploration and planetary science missions, and improve University involvement through targeted challenges. For example, Space Technology is working with the National Science Foundation to formulate the Space Robotics Challenge where NASA and National Science Foundation developed robots will be awarded to qualified institutions. The selected teams will have three years to improve the software and automation aspects of the Robonaut series robots. Centennial Challenges is working with the not-for-profit Space Center Houston and a team at NASA/JSC to manage the competition. The total prize purse for this challenge is $2.0M; and
- NASA is working with the Methuselah Foundation to support the Tissue Engineering Challenge in FY 2016, FY 2017, and FY 2018. This challenge will focus on the generation of tissue with cells performing functions of one of the four major organs (heart, lung, liver, kidney) and remaining alive long enough to advance scientific research capabilities. The winner of the first level of this challenge will work with the Center for Advancement of Science in Space (CASIS) and the NASA Centennial Challenges Program to develop an experiment to be performed on the ISS. Results of this challenge could potentially facilitate the development of major organs in microgravity for the benefit of humankind. The total prize purse for this challenge is $0.5M.
- Prize authority requested in this budget totals $3.1M.

## FLIGHT OPPORTUNITIES

Flight Opportunities enables the maturation of technologies by providing affordable access to space environments using commercially available suborbital flights. This helps fulfill the overall goal of advancing space technology to meet future mission needs while simultaneously fostering the growth of the commercial spaceflight market. The program achieves these objectives by selecting promising technologies from industry, academia, and government, and testing them on commercial suborbital launch vehicles. This approach takes technologies from a laboratory environment and advances their maturity through flight-testing, while also feeding the development of the spaceflight technologies and infrastructure created by the Flight Opportunities Program flight providers. The program supports flights for both externally funded payloads and NASA-funded technology payloads selected though NASA Research Announcements (NRAs). Space Technology also collaborates with other NASA programs to provide suborbital platform flights for research and/or technology demonstrations.

# SPACE TECHNOLOGY RESEARCH AND DEVELOPMENT

In support of NASA's overall mission, Flight Opportunities has facilitated the testing of technologies for exploration and the commercial utilization of space. To date, the program has selected over 160 technology payloads, with over 50 percent led by universities. Technologies include ones that will: validate mobility models for hopping/tumbling robots on asteroids; test a microgravity rock coring drill using microspines; test on-off gecko adhesive grippers; test 3D printers capable of printing electronics, as well as metal and metal/thermoplastic hybrid 3D printers; test water delivery and photographic verification systems to grow plants in lunar gravity; demonstrate enabling communications technologies for future low-cost small earth return vehicles; fabricate freeze-cast titanium foams in microgravity; test a novel IVA space suit; evaluate biosleeve gesture control interface for telerobotics; and evaluate a medical microgravity suction device and aqueous immersion surgical system . In FY 2015, the Flight Opportunities program flew 29 technology payloads over the course of five parabolic and eight commercial suborbital reusable launch vehicle (sRLV) test flights. Among the technologies tested, Masten Space Systems flew NASA's Jet Propulsion Laboratory's Fuel Optimal and Accurate Landing System Test Flights (FOALS). FOALS is part of JPL's landing technology and is now one-step closer for potential infusion into the Mars 2020 mission. Another successful test flight included UP Aerospace Corporation's launch of the SpaceLoft-9 with four payloads, including a Montana State University project designed to mature the technology readiness level of a radiation tolerant, reconfigurable computer system. An additional 18 payload flights spanning six flight campaigns are planned for early FY 2016. NASA on-ramped Near Space Corporation through its commercial flight vendor solicitation to integrate and fly technology payloads on commercial suborbital reusable platforms.

## Program Schedule

Specific timelines for deliverables and achievement major milestones vary from project to project, and depend on successful demonstration of experimental capabilities and the results of design, development, fabrication, analyses, and testing. Both GCD and TDMs are composed of uncoupled project elements. See more in the historic performance graphic below.

## Program Management & Commitments

| Program Element | Provider |
|---|---|
| Space Technology Research Grants | Provider: U.S. Universities<br>Lead Center: NASA HQ program executive, Level 2 GRC<br>Performing Center(s): Various<br>Cost Share Partner(s): N/A |
| NASA Innovative Advanced Concepts | Provider: Various<br>Lead Center: NASA HQ program executive<br>Performing Center(s): Various<br>Cost Share Partner(s): Cost sharing is encouraged |

# SPACE TECHNOLOGY RESEARCH AND DEVELOPMENT

| Program Element | Provider |
|---|---|
| CIF | Provider: NASA centers<br>Lead Center: NASA HQ program executive<br>Performing Center(s): All<br>Cost Share Partner(s): Cost sharing is encouraged |
| GCD | Provider: Various<br>Lead Center: NASA HQ program executive, Level 2 LaRC<br>Performing Center(s): Various<br>Cost Share Partner(s): Various |
| TDM | Provider: Various<br>Lead Center: NASA HQ program executive, Level 2 MSFC<br>Performing Center(s): Various<br>Cost Share Partner(s): Other NASA programs |
| SST | Provider: Various<br>Lead Center: NASA HQ program executive; Level 2 ARC<br>Performing Center(s): Various<br>Cost Share Partner(s): Air Force Research Laboratory, Various universities |
| Centennial Challenges | Provider: Various<br>Lead Center: NASA HQ program executive, Level 2 MSFC<br>Performing Center(s): Various<br>Cost Share Partner(s): External and Internal partners fund competition events; NASA supplies prize money |
| Flight Opportunities | Provider: Various<br>Lead Center: NASA HQ program executive; Level 2 AFRC<br>Performing Center(s): Various<br>Cost Share Partner(s): Various |

## Acquisition Strategy

Space Technology Research and Development uses a blended acquisition approach. Solicitations are open to the broad aerospace community to ensure engagement with the best sources of new and innovative technology. As such, projects are being performed by the Nation's highly skilled workforce in industry, academia, across all NASA centers, and in collaboration with other government agencies. Awards are based on technical merit, cost, programmatic alignment, and impact to the Nation's future space activities. NASA uses acquisition mechanisms such as broad agency announcements, NASA research announcements, Space Act Agreements, requests for proposals and prize competitions, with awards guided by priorities cited in the space technology roadmaps and by NASA mission directorates. Future solicitations particularly within GCD, Flight Opportunities, and SST will endeavor to use unfunded and funded Space Act agreements where these approaches are likely to yield acquisitions that are most efficient. The focus of these agreements will be to increase the level of public-private partnerships to perform future space technology development.

## MAJOR CONTRACTS/AWARDS

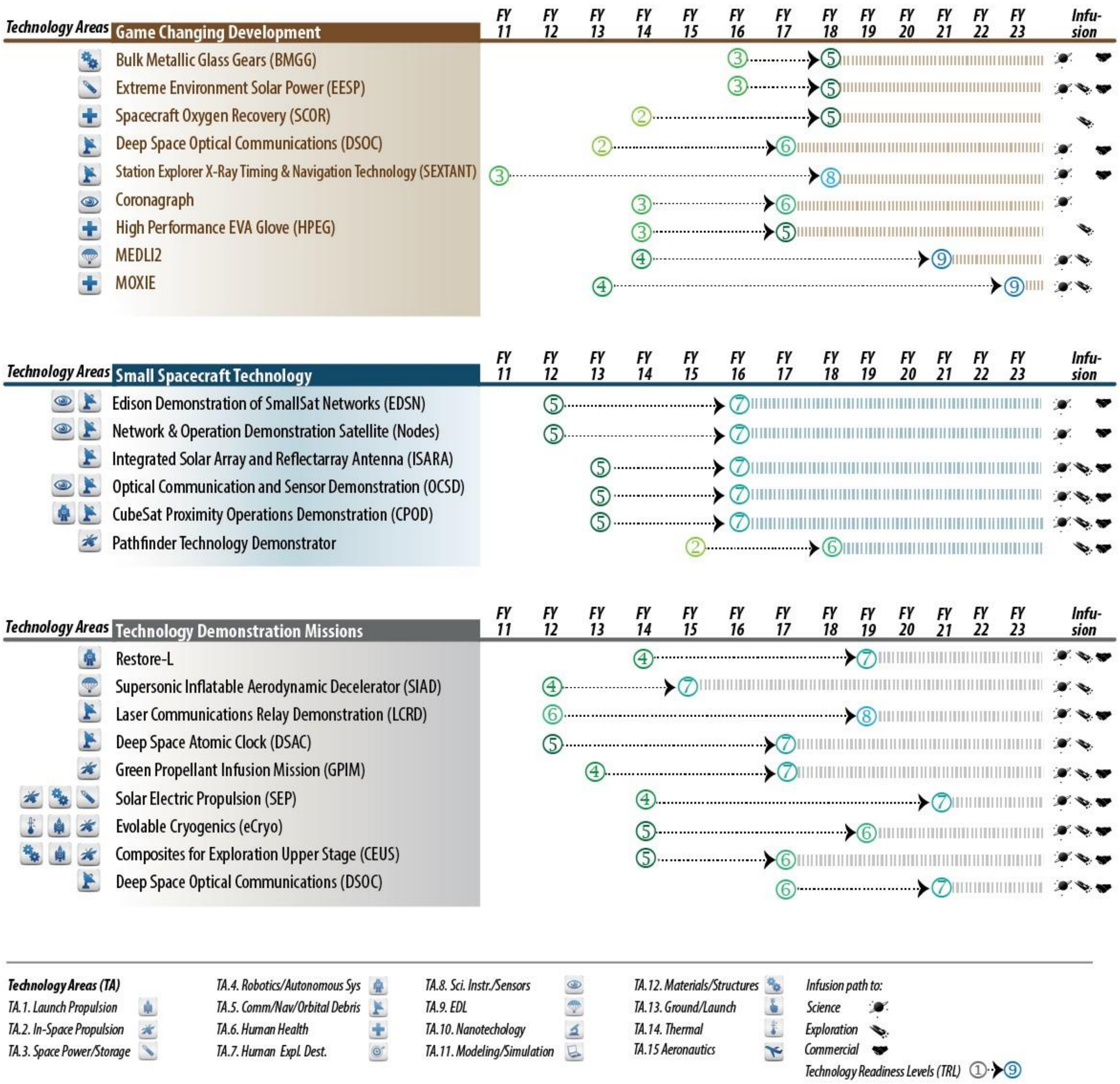
| Element | Vendor | Location (of work performance) |
|---|---|---|
| | TDMs | |
| LCRD | David Israel, Principal Investigator, GSFC; | Greenbelt, MD |
| DSAC | Todd Ely, Principal Investigator<br>California Institute of Technology, JPL | Pasadena, CA |
| SEP | Mike Barrett, Project Manager, GRC; GSFC; JPL; | Cleveland, OH; Greenbelt, MD;<br>Pasadena, CA |
| eCryo | Carol Ginty, Project Manager, GRC; MSFC, GSFC, KSC, ARC | Cleveland, OH; Huntsville, AL, Greenbelt, MD; Cape Canaveral, FL, Moffett Field, CA |
| GPIM | Ball Aerospace (Prime); Aerojet Rocketdyne Corporation; USAF Research Laboratory; USAF Space and Missile Systems Center; GRC; LaRC; KSC | Boulder, CO; Redmond, WA; Edwards, CA; Albuquerque, NM; Cleveland, OH; Cape Canaveral, FL |
| Restore-L | GSFC; KSC, Space Systems Loral, Motiv Space Systems | Greenbelt, MD; Cape Canaveral, FL; Pasadena, CA; Pasadena, CA |
| DSOC | JPL | Pasadena, CA |

## INDEPENDENT REVIEWS

Space Technology conducts Directorate Program Management Council reviews, and representatives from the Office of Chief Engineer, the Office of Safety and Mission Assurance, and the Office of Chief Financial Officer will assess performance during Agency-level Baseline Performance Reviews.

# Historical Performance

This technology investment overview identifies a subset of active Space Technology development efforts, illustrating core technology areas that aligned with the Space Technology roadmaps and anticipated technology maturation through the life cycle of the project leading to its potential use within NASA's existing and future science and exploration missions. By design, each of these technologies has significant utility for a variety of government and commercial users as well. All the projects listed below are on track to mature and deliver technology advancements in the timeframe specified. Specific timelines for deliverables and major milestones vary from project to project, and are dependent on successful capability demonstration.



# HUMAN EXPLORATION AND OPERATIONS

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Exploration | 3542.7 | 4030.0 | **3336.9** | 3529.7 | 4081.7 | 4243.6 | 4261.7 |
| Space Operations | 4625.5 | 5029.2 | **5075.8** | 4912.8 | 4529.7 | 4540.1 | 4697.6 |
| **Total Budget** | **8168.2** | **9059.2** | **8412.7** | **8442.5** | **8611.4** | **8783.7** | **8959.3** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

# HUMAN EXPLORATION AND OPERATIONS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Exploration | 3542.7 | 4030.0 | **3336.9** | 3529.7 | 4081.7 | 4243.6 | 4261.7 |
| Space Operations | 4625.5 | 5029.2 | **5075.8** | 4912.8 | 4529.7 | 4540.1 | 4697.6 |
| **Total Budget** | **8168.2** | **9059.2** | **8412.7** | **8442.5** | **8611.4** | **8783.7** | **8959.3** |
| Change from FY 2016 | | | **-646.5** | | | | |
| Percentage change from FY 2016 | | | **-7.1%** | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

NASA is working to expand human presence into the solar system, including eventually to the surface of Mars. The first steps of the Journey to Mars are well underway, with research into long-duration spaceflight continuing aboard the International Space Station (ISS), the development of NASA's next generation launch systems and crew vehicle, and investments in new technologies to increase the affordability, capability, and safety of exploration activities.

To enable this effort, NASA is advancing access to low Earth orbit by engaging U.S. commercial providers. Through FY 2015, Space Exploration Technologies Company (SpaceX) and Orbital ATK have flown a combined total of 10 successful cargo delivery flights to the ISS, including their 2 demonstration flights. By having two commercial partners for cargo, NASA minimized the impacts from the Orb-3 and SpX-7 losses. ISS was able to absorb both losses without immediate impacts to ISS operations and utilization. Utilizing the shift to the commercial paradigm, NASA also has entered into contracts with two industry partners to develop a U.S. commercial capability to transport crew to and from the station. In addition, NASA recently awarded Commercial Resupply Services 2 (CRS2) to SpaceX, Orbital ATK, and Sierra Nevada to provide cargo transportation services to the ISS.

Exploring deep space requires the capability to transport crew and large masses of cargo beyond low-Earth orbit. To accomplish this, NASA is developing a crew capsule, a heavy-lift launch vehicle, and supporting ground facilities and systems. The Space Launch System (SLS) leverages NASA heritage systems, thereby reducing risk. The Orion crew capsule will carry up to four humans to orbit, provide emergency abort capability, providing transit to cis-lunar space, sustain the crew while in space, and provide safe reentry from deep space. Upgraded ground operations capabilities will process flight hardware, assemble and launch the vehicles, and recover crew after the mission.

Before we can use these systems to safely send humans safely into deep space for extended missions, we must also continue the vital human health research already underway, develop key technologies, and enhance the supporting capabilities that NASA requires for mission success. The Human Exploration and Operations Mission Directorate (HEOMD) budget funds a portfolio of research, development, and operational programs to extend the boundaries of human space exploration and generate new scientific and technical knowledge. HEOMD utilizes a mix of NASA Civil Service expertise, conventional industrial contracts, milestone-based private sector capability developments and services, and international and U.S. commercial partnerships.

### Extending Human Presence into the Solar System: Enabling Multiple Destinations on the Journey to Mars

NASA is developing the capability for people to live and work safely beyond the Earth for extended periods in increasingly distant locations. In this new era, NASA is implementing a multiple destination exploration strategy, using a capability driven approach. This strategy leverages compelling near-term mission opportunities that enable incremental buildup of capabilities for more complex missions in the future, such as exploring Mars and its moons.

The cornerstone of our current efforts is the ISS, which has provided opportunities to investigate the challenges of future human spaceflight. What capabilities do we need for long-duration missions? What effects does the harsh environment of space have on the crew? How can we maximize the crew's health and performance on future deep-space missions? Research continues on the ISS to answer these questions and to validate exploration capabilities in an in-space environment, while maintaining close proximity to Earth.

To advance our ability to conduct a sustainable campaign of progressively more complex exploration missions, NASA will exploit the opportunities afforded by other locations such as cis-lunar space. In the volume of space around the Earth-Moon system, we can establish a proving ground to validate new technologies, hardware, and operations in deep space and microgravity environments. There, crews can assess mitigation techniques for health and performance, perform test operations of SLS and Orion, and demonstrate prototype systems.

As NASA incrementally lessens human reliance on Earth, cis-lunar space will provide a location from which we can mount missions to the more distant reaches of space, including expeditions to Mars. The distance and duration of these future missions requires that crew and transportation systems be completely independent of Earth. Logistics, power and propulsion systems, human factors, habitat, and operations, all these factors must be capable of supporting the autonomous operations necessary to travel millions of miles and spend many months in space. Our strategy is to move from Earth-reliant research and technology development to the proving ground of cis-lunar space to achieve Earth-independent exploration capability for human mission durations that enable us to reach Mars and other destinations in the solar system.

### Earth Reliant Activity

The ISS offers a unique platform for NASA and its international partners to learn how to live and work in space. Research, technology demonstrations, tests, and experiments on the ISS continue to advance the capabilities required for future long-duration missions. NASA is making technological advances aboard the ISS in autonomous rendezvous and docking, advanced communications systems, human health and behavior in space, habitat, and space suit systems, as well as in basic research in biological and physical sciences. For example, NASA is capitalizing on the extraordinary opportunity to study identical twins during Scott Kelly's yearlong stay aboard the ISS. Scott Kelly and Mark Kelly are genetically almost the same and by studying one astronaut on the Earth, while one remains in space for an entire year provides an unprecedented comparison of spaceflight on humans.

# HUMAN EXPLORATION AND OPERATIONS

Building on the success of NASA's partnerships with commercial industry to date, in spring of 2015 NASA selected 12 Next Space Technologies for Exploration Partnerships (NextSTEP) to advance concept studies and technology development projects in the areas of advanced propulsion, habitation and small satellites.

NASA has partnered with the Center for the Advancement of Science in Space (CASIS) to exploit the National Lab portion of the ISS for commercial and other government agency research, allowing researchers and entrepreneurs representing a wide range of disciplines to develop groundbreaking technologies and products in a microgravity environment. Not only is the ISS a vehicle capable of supporting a broad range of research and technology development, it is also capable of serving as a test bed for new business relationships. While CASIS is broadening the non-traditional demand-side use of the ISS, NASA is assisting new commercial service providers in increasing research capabilities and offering services on the supply-side. In FY 2015, NASA signed agreements with five additional commercial firms to operate hardware on the ISS on a fee-for-service basis. This includes a hyperspectral instrument (Teledyne Brown Engineering) and materials science exposed platform (Alpha Space and Technology) to be attached externally on the ISS; a microfluidics stem cell research module (HNu nanoPoint); a suite of biological sciences hardware (Bioserve), and a multi-specimen centrifuge (Techshot) inside the ISS. The leading provider of research services on ISS, NanoRacks, last year saw the launch of their exposed facility, the first commercially developed and funded external research platform. Finally, NASA and Bigelow Aerospace are each benefitting from sharing expertise, costs, and risks to pursue the mutual goal of demonstrating the potential of an inflatable habitat on the ISS, (the Bigelow Expandable Activity Module (BEAM)).

NASA and the U.S. space transportation industry are well on the way to developing an affordable capability to carry crew to the ISS by the end of 2017, bolstering American leadership while eliminating reliance on the Russian Soyuz to transport American astronauts. This competitive commercial approach, versus a traditional NASA-owned and operated system, allows the Agency to reduce costs, improve affordability and sustainability, and stimulate the private sector space industry. With U.S. commercial industry providing cargo resupply services to the ISS, NASA is funding development activities for commercial crew systems. The Agency will purchase commercial crew transportation services using the same model used for cargo services.

## Proving Ground Activity

Continuing extensive development efforts, NASA is focused on working toward a capability to launch the first Exploration Mission (EM-1). Utilizing its first flight test and resulting data, Orion is continuing to design, development, and test to prepare for its first pairing with SLS. Launching atop SLS, Orion will travel into space for a 25-day journey beyond the Moon and back to Earth. NASA is working toward the first crewed mission (EM-2), scheduled to launch in Fiscal Year 2021 (FY 2021), with a commitment to launch no later than 2023.

Exploration Missions of SLS and Orion and related capabilities will increase our ability to operate for extended periods in the proving ground of cis-lunar space, with the objective of demonstrating the capability to conduct Mars-class missions beginning in the 2030s. An early mission in the proving ground of cis-lunar space, the Asteroid Redirect Mission (ARM), would identify and capture a target asteroid; redirecting it into a retrograde orbit around the moon for rendezvous and sampling by astronauts conducing spacewalks out of the Orion crew vehicle. Harnessing new solar-electric propulsion (SEP)-based systems and using the capability of the SLS and Orion, ARM will demonstrate key exploration capabilities as the Agency reaches farther into deep space.

# Human Exploration and Operations

To travel beyond low Earth orbit, NASA requires enhanced research and technological capabilities. Researchers are studying the effects of long-duration space exploration on humans in an effort to safeguard crews and assure mission success. New technologies are being infused into systems and capabilities geared toward supporting eventual missions to Mars including solar electric propulsion systems, deep space habitation systems, in-situ resource utilization, and operations with reduced logistics dependence. The demands of deep space require assuring robust communications and data download, and increasingly complex navigation systems. These efforts, conducted in the proving ground, continue to be critical priorities within HEOMD's Space Operations and Explorations budgets, and will enable NASA to extend our progress along the capability driven framework while maintaining reliable and affordable access to space.

NASA is working with industry to develop concepts, technologies, and systems to enable a cis-lunar habitation capability that will lead to a long-duration habitat for Mars missions and may be applicable to future commercial habitats in Earth orbit. The second phase of NextSTEP Broad Agency Announcements are being utilized to leverage and stimulate the development of commercial habitats in low Earth orbit and will result in further developed habitation concepts with eventual flight demonstrations in space. Development and testing of key habitation systems (such as environmental control and life support, radiation protection, and logistics reduction) through a public-private partnership are currently planned lead to a prototype habitat for ground testing by 2018

### Earth-Independent Activity

To enable space travel that is Earth independent, NASA will continue to incrementally and progressively, expand capabilities and distance from Earth. We will need to complete development of whole new types of entry and landing systems, partial-gravity countermeasures, and long-duration surface systems such as in-situ resource utilization (ISRU) and in-space manufacturing. Activities are underway in these areas in collaboration with the Science Mission Directorate (SMD) and the Space Technology Mission (STMD) Directorate. For example, the HEOMD and the STMD are jointly funding the Mars Oxygen ISRU Experiment (MOXIE) on the SMD's Mars 2020 rover mission, which will produce oxygen from Martian atmospheric carbon dioxide

### Spaceflight Services

The HEOMD portfolio also includes essential services needed to conduct the Agency's human and robotic exploration. These include Space Communications and Navigation (SCaN), Launch Services acquisition, astronaut selection and training, crew health and safety, Rocket Propulsion Test (RPT), and related activities.

# EXPLORATION

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Exploration Systems Development | 3211.5 | 3680.0 | **2859.5** | 2922.5 | 3061.6 | 3092.2 | 3142.3 |
| Exploration Research and Development | 331.2 | 350.0 | **477.3** | 607.2 | 1020.1 | 1151.4 | 1119.5 |
| **Total Budget** | **3542.7** | **4030.0** | **3336.9** | **3529.7** | **4081.7** | **4243.6** | **4261.7** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

# EXPLORATION

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Exploration Systems Development | 3211.5 | 3680.0 | **2859.5** | 2922.5 | 3061.6 | 3092.2 | 3142.3 |
| Exploration Research and Development | 331.2 | 350.0 | **477.3** | 607.2 | 1020.1 | 1151.4 | 1119.5 |
| **Total Budget** | **3542.7** | **4030.0** | **3336.9** | **3529.7** | **4081.7** | **4243.6** | **4261.7** |
| Change from FY 2016 | | | **-693.1** | | | | |
| Percentage change from FY 2016 | | | **-17.2%** | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

**Lockheed Martin technicians lift the Orion Crew Module Adapter Structural Test Article at NASA Glenn Research Center (GRC)'s Plum Brook Station. The adapter will connect Orion's crew module to a service module provided by the European Space Agency (ESA) and Airbus Defense & Space.**

As NASA shapes the future architecture of human space exploration, the Agency has developed a sustainable, pioneering approach of progressively expanding capabilities and distance with an objective of extending human presence into the solar system and to the surface of Mars. Human Exploration and Operations Mission Directorate (HEOMD) programs continue to develop a robust core set of evolving capabilities within the Exploration budget, intended to ensure flexibility, affordability, and sustainability in the Nation's human spaceflight program, while using the International Space Station (ISS) as a research testbed for long-duration spaceflight. This approach provides the Agency adequate adaptability to carry out increasingly complex missions to a range of destinations over time.

HEOMD's Exploration Systems Development programs are creating the first components of this architecture for human exploration beyond low Earth orbit, Orion, Space Launch System (SLS), and Exploration Ground Systems (EGS), will take us to the proving ground of cis-lunar space (the volume of space around the Moon) to conduct deep- space long-duration missions to test systems and concepts for further exploration.

Extending human presence into deep- space requires expansion of technical and scientific knowledge to tackle complex problems and devise creative new solutions to meet demands never before encountered by humans or crewed spacecraft. NASA must understand and mitigate the effects of long-term human exposure to space and the Human Research Program (HRP) is conducting research on the ISS toward this end. NASA's Advanced Exploration Systems (AES) is also developing the technologies and maturing the systems required for deep-space missions.

For more programmatic information, go to: http://www.nasa.gov/directorates/heo/home/index.html.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| Mandatory Funding (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| ESD | -- | -- | 173.0 | -- | -- | -- | -- |

Consistent with the FY 2016 Consolidated Appropriations Act, the Budget realigns the Commercial Crew Program (CCP) from the Exploration account to the Space Operations account within the Space Transportation Theme for increased synergy with the ISS program.

Orion changed the Ascent Abort Test (AA-2) implementation from contractor-led effort to Government-led effort and moved the test date from 2019 to 2020. AA-2 will still meet all test objectives.

AES, working closely with the private sector, will begin development of system concepts and integrated subsystems for a cis-lunar habitat and systems that will enable extended duration human missions in the proving ground of cis-lunar space in preparation for human missions into deep space. AES will continue the existing acquisition strategy for the cis-lunar habitat and systems by building upon the NextSTEP public-private partnerships, which seek to leverage additional public sector investments to develop commercial habitats in low Earth orbit. Additionally, HEOMD is consolidating technology activities spread across multiple program into AES in order to better align the Directorate's organizational and management structure.

To align upcoming HEOMD exploration and technology activities, some cross cutting studies and initiatives that had been conducted in other programs have now been realigned to AES enabling effective coordination between research and technology capabilities required to support to robotic, Extra-Vehicular Activity (EVA), Asteroid Redirect Mission (ARM), and future exploration missions.

ESD is funded in part with mandatory funding, Orion ($66.4M), SLS ($80.4M), and EGS ($26.2M).

## ACHIEVEMENTS IN FY 2015

Following the Exploration Flight Test 1 (EFT-1) flight in December 2014, the Orion program continued to analyze the data collected during EFT-1, met all test objectives, demonstrated design and performance, and revealed risks in systems such as the heat shield, parachute system, and crew module up-righting system, which are being addressed. During EFT-1, Orion orbited Earth twice, reaching an altitude of approximately 3,600 miles, roughly 15 times farther into space than the orbit of the ISS. Having sent Orion to such a high altitude allowed the spacecraft to return to Earth at speeds near 20,000 miles per hour. The spacecraft's return at this speed exposed the heat shield to temperatures close to what it will endure when returning from the vicinity of the Moon for follow-on exploration missions and NASA's ARM. Orion continues design, development, and testing for EM-1 and EM-2.

SLS performed the RS-25 engine test for the SLS Core Stage, Booster Qualification Motor-1 test, and integrated avionics into the software integration test facility as well as continued construction of structural test articles. SLS completed its Critical Design Review (CDR) progressing toward final design, fabrication, and qualification.

EGS successfully completed the landing and recovery operations of the Orion crew module after the EFT-1 splashdown. The program continued modifications to Shuttle and Apollo-era Systems necessary for future NASA space exploration beginning with EM-1 and EM-2. EGS began installing ground support equipment and completing structural and facility modifications on the mobile launcher. In preparation for processing SLS, the adjustable high-bay platform construction continued as well as completing modifications for infrastructure and propellant gas systems. EGS continued installing and upgrading software to end-to-end spaceport command and control system applications and displays required in ground processing facilities.

AES developed foundational technologies and high-priority capabilities that are building blocks for future human space missions. AES studied options to augment Orion's habitation and EVA deep space capabilities, developed three payloads to understand the large-scale spread of fire in microgravity, continued developing secondary CubeSat payloads to fly on SLS, and completed the Concept Review for the Asteroid Redirect Robotic Mission (ARRM) under the ARM effort.

FY 2015 marked the launch of astronaut Scott Kelly and cosmonaut Mikhail Kornienko to the ISS, where they are living for an entire year in a joint U.S./Russian mission—the longest mission ever assigned to a U.S. astronaut. The 12-month mission provides a greater understanding of what counter measures and conditioning is required for further exploration missions beyond six months. In conjunction, with the one-year mission, HRP is exploiting a rare opportunity to study identical twins Scott and Mark Kelly. Examining one astronaut on the ground while the other is in space provides insight into the way genes and proteins in the cells are affected during spaceflight.

## WORK IN PROGRESS IN FY 2016

In October 2015, Orion completed its CDR board, ensuring its readiness to progress to the next phase of the development life cycle: full-scale fabrication, assembly, integration, and test. In FY 2016, Orion will continue to focus on preparing for EM-1, an uncrewed test flight to distant retrograde lunar orbit, and the first pairing with SLS. This mission will provide the program with new and increased fidelity data, which, combined with information gained from EFT-1, will validate spacecraft design and operations for crewed EM-2 in the 2020s.

SLS will complete testing on the Launch Vehicle Stage Adapter structural test article, Interim Cryogenic Propulsion Stage (ICPS) structural test article, and Orion Stage Adapter structural test article. SLS will also conduct SLS Booster Qualification Motor-2 test at Orbital ATK. SLS will complete testing of the EM-1 flight RS-25 engines.

EGS will continue progress on ground support systems, completing CDR, software upgrades, Vehicle Assembly Building (VAB) adjustable high-bay platform construction, mobile launcher, pad, and crawler transporter modifications. These ground systems are necessary for future NASA exploration missions, beginning with EM-1 and EM-2.

AES activities will continue to support the Bigelow Expandable Activity Module (BEAM), scheduled to arrive at the ISS in 2016 to demonstrate inflatable structures technology for deep space habitats. AES will launch the first of three Spacecraft Fire Safety Experiments (Saffire-1) to ISS investigating the spread of large-scale fires in space. AES is also developing and testing highly reliable life support systems, such as atmosphere recovery systems, increased water recovery, and smaller monitoring systems, which are designed for deployment on ISS, Orion, and initial habitation capabilities in cis-lunar space.

AES will collaborate with ISS and Exploration Systems Development (ESD_ and through public-private partnerships under the NextSTEP Broad Area Announcements on promising areas to enable next-generation habitat capabilities for long-term missions.

ARM is progressing towards a System Definition Review (SDR) for the robotic mission, and is leveraging development of synergistic capabilities for In-Space Robotic Servicing (ISRS), such as automated rendezvous and docking sensors and autonomous robotic manipulators. NASA continues planning for a mid-2020s crewed mission concept development, including discussions of potential U.S. industry and international partnerships.

HRP will conclude data collection from the one-year joint US/Russian ISS mission. This collection of data will provide NASA a first look into the effects of longer mission durations on ocular health, immune and cardiovascular systems, cognitive performance testing, and countermeasure effectiveness against bone and muscle loss.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

Orion, SLS, and EGS will continue to prepare for the EM-1 mission, the first pairing of Orion and SLS. This multi-day flight will provide the program with data, which, combined with data gained from EFT-1, will validate spacecraft design and operations. Orion will finalize EM-1 design and development engineering; complete the structural build; begin assembly, integration, and testing of the EM-1 crew module; and complete the parachute development test campaign. EGS will finalize efforts in the VAB, the launch pad, and other ground support systems to ensure readiness for EM-1 support. SLS will prepare for final major element tests and hardware production for EM-1, and ship hardware for integration and testing.

As NASA works to extend human space exploration beyond low Earth orbit, AES will continue to develop in-space manufacturing technology, reliable life support, deep space habitats, crew mobility systems, advanced in-space propulsion, and advanced space suit technologies to support future human spaceflight missions. ARM will continue robotic development to confirmation, or Key Decision Point (KDP)-C, and planning of a crewed mission, including for hardware deliveries (common sensors, docking, and EVA accommodations) to the robotic mission.

HRP will re-compete its external institute cooperative agreement for the first time in 20 years. The new initiative, a public-partnership Translational Research Institute, will lead a national effort in translating cutting-edge emerging terrestrial biomedical research and technology development into applied spaceflight human risk mitigation strategies for exploration missions. HRP will continue research in support of long-duration health of the crew and risk mitigations, and by FY 2017 one of those risks, renal stone formation, will be retired because a validated treatment will be in place.

# EXPLORATION

## Themes

### EXPLORATION SYSTEMS DEVELOPMENT

Programs within the ESD theme are developing the core capabilities required to implement NASA's multi-destination strategy. The SLS program is developing the heavy-lift vehicle that will launch the crew vehicle, other modules, and cargo for deep space missions. The Orion program is developing the vehicle that will carry the crew to orbit, provide emergency abort capability, sustain the crew while in space, and provide safe reentry from deep space return speeds. The EGS program is working to develop the necessary launch site infrastructure to prepare, assemble, test, launch, and recover the SLS and Orion flight systems. NASA Headquarters is integrating programs to streamline decision-making processes, and enable an affordable long-term human exploration program.

### EXPLORATION RESEARCH AND DEVELOPMENT

Exploration Research and Development (ERD) consists of two programs, AES and HRP, which map directly to the National Space Policy and the NASA Authorization Act of 2010. AES develops exploration technologies applicable to multiple missions and destinations to reduce risk, lower lifecycle cost, and validate operational concepts for future human missions to deep space. HRP researches the effects of spaceflight on humans and develops countermeasures to lessen the effects of the hostile space environment on human health and performance. HRP utilizes ground research facilities, the ISS, and analog environments to achieve this goal.

# ORION PROGRAM

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Crew Vehicle Development | 1179.7 | 1251.5 | **1109.3** | 1109.4 | 1113.4 | 1124.6 | 1142.7 |
| Orion Program Integration and Support | 10.5 | -- | **10.5** | 10.5 | 10.5 | 10.5 | 10.7 |
| **Total Budget** | **1190.2** | **1270.0** | **1119.8** | **1119.9** | **1123.9** | **1135.1** | **1153.3** |
| Change from FY 2016 | | | **-150.2** | | | | |
| Percentage change from FY 2016 | | | **-11.8%** | | | | |

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*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

**Inside the Launch Abort System Facility at NASA's Kennedy Space Center (KSC) in Florida, workers are preparing the Orion spacecraft that flew on EFT-1 in 2014 for transport to a laboratory to perform additional testing. The flown EFT-1 spacecraft is helping NASA finalize the Orion designs. Orion will next launch atop NASA's SLS rocket on EM-1)**

The Orion program is continuing to take major steps toward transporting humans safely to deep space and back. The first of two uncrewed flight tests planned for the Orion spacecraft, EFT-1, flew in December 2014, paving the way for astronauts to venture beyond low Earth orbit for the first time since the Apollo program in the 1960s and early 1970s. The second uncrewed flight test, EM-1, is targeted for 2018.

This capsule-shaped vehicle has a familiar look, but its crew and service modules, spacecraft adapter, and launch abort system incorporate numerous technology advancements and innovations. Orion's launch abort system can activate within milliseconds to carry the crew from harm's way and position the module for a safe landing. The spacecraft's propulsion, thermal protection, avionics, and life support systems will enable extended duration missions beyond low Earth orbit and into deep space. Its modular design will be capable of integrating additional new technical innovations as they become available.

Orion design, development, and testing (including the flight tests) will have the spacecraft ready to carry crew no later than FY 2023. Future flights of SLS and the Orion crew vehicle into cis-lunar space will extend our capability for human deep space exploration operations, reducing the overall risk as mission durations extend. In addition, Orion will conduct the crewed rendezvous portion of the proposed ARM, which will find, capture, redirect, and sample a near-Earth asteroid. This series of activities will use the proving ground of cis-lunar space to develop the systems and procedures necessary for Mars-class missions.

For further programmatic information, go to: http://www.nasa.gov/orion.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Mandatory Budget Authority** | -- | -- | 66.4 | -- | -- | -- | -- |

Orion is funded in part with mandatory funding.

To reduce overall program schedule risk, Orion changed AA-2 implementation from a contractor-led to a Government-led effort and moved the test date from 2019 to 2020. The AA-2 flight will still meet all primary test objectives.

# Program Elements

## ORION PROGRAM INTEGRATION AND SUPPORT

Orion program integration and support activities manage the SLS and EGS program interfaces. This effort is critical to ensuring Orion's performance meets technical and safety specifications, and supports programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the Orion integration effort is vital to managing interfaces with other HEOMD activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across the three programs enables the Agency to avoid potential design overlaps, schedule disconnects, and cost issues.

## CREW VEHICLE DEVELOPMENT

See the Crew Vehicle Development section.

# CREW VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Prior | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 | BTC | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Formulation | 3785.8 | 885.7 | 0.0 | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4671.5 |
| Development/Implementation | 3.0 | 294.0 | 1247.7 | **1109.3** | 1109.4 | 1113.4 | 827.5 | 542.2 | 365.5 | 6612.0 |
| Operations/Close-out | 0.0 | 0.0 | 0.0 | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **2016 MPAR LCC Estimate** | **3788.8** | **1179.7** | **1247.7** | **1109.3** | **1109.4** | **1113.4** | **827.5** | **542.2** | **365.5** | **11283.5** |
| **Total Budget** | **3785.8** | **1179.7** | **1251.5** | **1109.3** | **1109.4** | **1113.4** | **1124.6** | **1142.7** | **0.0** | **11816.4** |
| Change from FY 2016 | | | | **-142.2** | | | | | | |
| Percentage change from FY 2016 | | | | **-11.4%** | | | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

*2016 MPAR LCC estimate includes funding from all appropriations, Exploration and Construction and Environmental Compliance and Restoration. Budget line reflects funding from the Exploration appropriation only.*

# CREW VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

**Engineers at NASA's Michoud Assembly Facility (MAF) in New Orleans, LA, perform the first weld on the Orion spacecraft pressure vessel for EM-1 on Sept. 5, 2015. This is the third Orion pressure vessel built. Engineers continue to refine the design, reducing the number of welds from 33, on the first pressure vessel, to seven on the current one, saving 700 pounds of mass.**

## PROJECT PURPOSE

As NASA reaches beyond low-Earth orbit to destinations across the solar system, the Orion crew vehicle took its first steps toward deep space with the launch of EFT-1. Orion will be capable of transporting humans to multiple destinations beyond our Moon and into deep space, sustaining them longer than ever before, and returning them safely to Earth. Drawing from more than 50 years of human spaceflight R&D and stimulating new and innovative manufacturing and production capabilities, Orion's design will meet the evolving needs of our Nation's space program, and push the envelope of human exploration for decades to come.

For further programmatic information, go to http://www.nasa.gov/orion.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

EFT-1 launched in 2014, and was a major milestone for the Orion program because it provided the opportunity to test the most vulnerable and untried systems and significantly improved the understanding of performance and risk in those areas. The results of EFT-1 have led to the reconsideration or modification of the manufacture, assembly, and test processes for the Orion vehicle and will ultimately lead to a more robust, reliable, and reproducible human spaceflight capability.

The program is addressing and implementing many of the lessons learned from EFT-1, but work is continuing to either fully resolve or implement improved designs for the EM-1. The program will implement design improvement beginning in FY 2016 and continuing into FY 2017. One prominent example is the heat shield design based on the Apollo Crew Module. Like Apollo, Orion experienced issues with both the manufacture and performance of the monolithic Avcoat heat shield on EFT-1. The shield cracked during the curing and integration process that led to handling and repair delays causing an unacceptable margin on structural performance. To mitigate these issues for future flights including EM-1 and EM-2, the re-engineering of the Orion heat shield into block sections will allow production that is more manageable for curing and assembly. These necessary improvements have positive impacts on the design, integration, and cost of the overall mission.

The program also changed the strategy for AA-2 implementation from a contractor-led to Government-led effort. Effective use of civil service skills and talents was the primary driver for this change. The

# CREW VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
| --- | --- | --- |

program has initiated a rigorous process to ensure capture of test objectives and schedule considerations to maximize the benefit of this strategic decision as forward progress continues.

The program also advanced through several major milestones, passing the KDP-C process, establishing an Agency Baseline Commitment, and completing their program-level CDR. These milestones matured the technical baseline, cost, and schedule, leading to better understanding of activities, timelines, requirements, and their phasing baselines in FY 2016 and 2017.

## PROJECT PARAMETERS

Orion will be able to carry a crew of four astronauts beyond Earth orbit and provide habitation and life support for up to 21 days. The spacecraft's three components are the crew module, service module, and launch abort system (LAS), with a separate adapter to connect the spacecraft and launch vehicles. While the module has a familiar visual shape, its interior and exterior capabilities far exceed any geometrically similar predecessors. The state of the art crew systems will provide a safe environment within which to live and work for long durations far from Earth. Orion's advanced heat shield will protect the crew from reentry heating during a high-speed return from beyond Earth orbit – heating that will exceed that experienced by human spacecraft in over four decades. The service module is comprised of a crew module adapter and the ESA-designed and developed service module section, and together they provide in-space power, propulsion, and other life support systems. On a tower atop the crew module sits the LAS, which, in the event of an emergency during launch or climb to orbit, will activate within milliseconds to propel the crew module away from the launch vehicle to safety. The abort system also provides a protective shell that shields the crew module from dangerous atmospheric loads and heating during ascent. Once Orion is out of the atmosphere and safely on its way to orbit, the spacecraft will jettison the LAS.

## ACHIEVEMENTS IN FY 2015

Since the successful EFT-1 mission, the Orion program has continued to analyze the data collected during the flight, which met all test objectives, demonstrated design and performance, and quantified risks in systems such as the heat shield, parachute system, crew module up-righting system, and many others. During EFT-1, Orion orbited Earth twice, reaching an altitude of approximately 3,600 miles, roughly 15 times farther into space than the orbit of the ISS. Having sent Orion to such a high altitude allowed the spacecraft to return to Earth at speeds near 20,000 miles per hour. The spacecraft's return at this speed exposed the heat shield to temperatures close to 80 percent of what it will endure when returning from the vicinity of the Moon during exploration missions including NASA's proposed ARM.

With completion of the first flight test and the resulting data, Orion continued design, development, and testing, focused on EM-1 and EM-2. Work on the EM-1 crew module pressure vessel continued with the completion of machining and delivery of all EM-1 components to the MAF, completion of nearly all pathfinder welds, and the first EM-1 weld. The Integrated Test Lab implementation continued with completion of the mockup assembly and cold plate installations, and with the start of first string Power Distribution Units testing in late summer. Orion's work on European Service Module (ESM) Structural Test Article (E-STA) continued with the start of assembly and testing at Thales Alenia Space Italia.

# CREW VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

## WORK IN PROGRESS IN FY 2016

In FY 2016, the program will continue to focus on preparing for Orion's EM-1 mission, an uncrewed test flight to distant retrograde lunar orbit, and the first pairing with SLS. This multi-day mission will provide the program with new and increased fidelity data, which, combined with information gained from EFT-1, will validate spacecraft design and operations. Early in FY 2016, Orion completed its CDR, ensuring Orion's readiness to progress to the next phase of the development life cycle: full-scale fabrication, assembly, integration, and test.

Work will continue on various components for the EM-1 flight test. The program will complete EM-1 crew module pressure vessel welding operations and ship it to KSC, where a series of proof and leaks test on the EM-1 crew module will take place in the second half of the year. Assembly and testing of the spacecraft will progress throughout FY 2016 at KSC. Orion will conduct its CDR on the heat shield design for EM-1. This CDR includes data resulting from the ongoing thermal testing and ground test article water impact testing at Langley Research Center (LaRC), using the flight EFT-1 heat shield for enhanced fidelity. This will allow EM-1 heat shield fabrication to begin later in the fiscal year. The final parachute test flight will be carried out in January 2016 and signal the move forward to flight qualification testing and acceptance.

Activities surrounding the ESM began to accelerate immediately with delivery of the E-STA to NASA Plum Brook Station test facility in mid-November. E-STA testing at Plum Brook is complete early in FY 2017. ESA will quickly kick-off its CDR in the second quarter of FY 2016, leading to the final board in the early third quarter. In the interim, the EM-1 orbital maneuvering system engine is complete for shipment to ESA for continued integration work.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

FY 2017 will culminate in mating of the EM-1 and ESM, Crew Module Adapter (CMA), Crew Module (CM), and LAS at KSC. Each module will go through its individual assembly, integration, and test followed by sequential mating and testing.

In the first quarter of FY 2017, the ESM is completing final integration and test in Bremen, Germany before shipping to KSC. At KSC, the ESM is mating with the CMA assembly. The structural assembly of the CMA is complete in FY 2016, but test and integration continues through the first half of FY 2017 before mating to the ESM. The mated ESM and CMA form the integrated Service Module. The next step is to attach the service module to the solar array panels for static and dynamic testing. Following removal of the panels after testing, mating of the integrated ESM with the CM occurs. After mating, the spacecraft is prepared for checkout, packaging, and shipping to Plum Brook Station for final thermal vacuum and acoustical vibration testing.

Before mating to the integrated service module, the CM assembly and integration is completed. This includes installation of the thermal protection system, including the heat shield, backshell, and Forward Bay Cover; the recovery systems including, the CM Uprighting System and parachute system and associated pyrotechnics; the avionics, software, and, harnessing; structural support, as well as fluids handling and other required flight systems. Although not integrated into Orion stack in 2017, the inert

# CREW VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

LAS is preparing for stacking operations. Forward work for EM-2 will begin in parallel to these EM-1 integration efforts in FY 2017 as well.

## SCHEDULE COMMITMENTS/KEY MILESTONES

| Milestone | Confirmation Baseline Date | FY 2017 PB Request |
|---|---|---|
| System Definition Review (SDR | | Aug 2007 |
| Preliminary Design Review (PDR) | | Aug 2009 |
| KDP-A, Formulation Authorization | Feb 2012 | Feb 2012 |
| Resynchronization Review | | Jul 2012 |
| KDP-B | Q1 FY 2013 | Jan 2013 |
| Delta PDR | Q4 FY 2013 | Aug 2014 |
| EFT-1 Launch | Dec 2014 | Dec 2014 |
| KDP-C, Project Confirmation | FY 2015 | Sept 2015 |
| CDR | Oct 2015 | Oct 2015 |
| EM-1 Launch Readiness | FY 2018 | FY 2018 |
| AA-2 Flight Test | FY 2020 | FY 2020 |
| EM-2 Launch Readiness | FY 2023 | FY 2023 |

## Development Cost and Schedule

| Base Year | Base Year Develop-ment Cost Estimate ($M) | JCL (%) | Current Year | Current Year Develop-ment Cost Estimate ($M) | Cost Change (%) | Key Milestone | Base Year Milestone Data | Current Year Milestone Data | Milestone Change (mths) |
|---|---|---|---|---|---|---|---|---|---|
| 2015 | 6,768.4 | 70 | 2016 | 6,612 | -2.3 | EM-2 | Apr-23 | Apr-23 | 0 |

*Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.*

# CREW VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

## Development Cost Details

| Element | Base Year Development Cost Estimate ($M) | Current Year Development Cost Estimate ($M) | Change from Base Year Estimate ($M) |
|---|---|---|---|
| **TOTAL:** | **6,768.4** | **6,612** | **-156.4** |
| Mission Operation | 281.6 | 273.3 | -8.3 |
| Program Management | 671.5 | 634.4 | -37.1 |
| Safety and Mission Assurance | 191.4 | 182.4 | -9.0 |
| Spacecraft | 3205.1 | 3182.1 | -23.0 |
| Systems Engineering and Integration | 539.3 | 501.7 | -37.6 |
| Test and Verification | 460.6 | 426.9 | -33.7 |
| Other | 1418.9 | 1411.3 | -7.6 |

## Project Management & Commitments

| Element | Description | Provider Details | Change from Baseline |
|---|---|---|---|
| CM | The transportation capsule provides a safe habitat for the crew as well as storage for consumables and research instruments, and serves as the docking port for crew transfers. | Provider: Johnson Space Center (JSC)<br>Lead Center: JSC<br>Performing Center(s): Ames Research Center (ARC), GRC, JSC, and LaRC<br>Cost Share Partner(s): N/A | None |
| Service Module | The service module supports the crew module from launch through separation before reentry. | Provider: JSC<br>Lead Center: JSC<br>Performing Center(s): ARC, JSC, LaRC, and GRC<br>Cost Share Partner(s): ESA | None |
| LAS | The LAS maneuvers the crew module to safety in the event of an emergency during launch or climb to orbit. | Provider: JSC<br>Lead Center: LaRC<br>Performing Center(s): JSC, LaRC, and MSFC<br>Cost Share Partner(s): N/A | None |

# CREW VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

## Project Risks

| Risk Statement | Mitigation |
|---|---|
| If: The existing barter agreement between NASA and ESA does not offset the cost of Orion's service module work package 2, for EM-2,<br>Then: Funding offsets would be required or the schedule would slip. | Orion will continue to try to identify possible barter elements from the entire NASA portfolio to offset the cost of work package 2. |
| If: The Orion test and verification plan increases the reliance on spacecraft component and subsystem testing,<br>Then: There is a potential of increased risk of technical issues in higher-level systems. | Orion will continue to develop guidelines to implement the component qualification approach, validate the proposed test campaign to meet flight test objectives to identify gaps and risks, and assess and reduce risk to flight hardware. |
| If: Integrated software and avionics testing requires more work than planned,<br>Then: The Integrated Test Lab (where which this testing is performed) may not have sufficient capacity at peak testing times. | Orion manages the timing of the tests to reduce the peak workloads and to seek other testing capacity using other existing avionics labs. |

## Acquisition Strategy

NASA is using a competitively awarded contract to Lockheed Martin Corporation for Orion's design development, test, and evaluation. The contract awarded in 2006 and reaffirmed in 2011 as part of reformulating the Orion Crew Exploration Vehicle as the Orion program. Orion then adjusted this contract in order to meet NASA and HEOMD requirements, such as the current flight test plan and the EM-2 flight readiness date.

NASA signed an Implementing Arrangement with ESA to provide a service module for the Orion spacecraft EM-1. Incorporating the partnership with ESA also required a contract modification with Lockheed Martin to integrate the ESA-provided service module with the Lockheed Martin portion of the spacecraft.

### MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Orion Design and Development | Lockheed Martin | Littleton, CO |

# CREW VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| System Requirements Review (SRR) | Standing Review Board (SRB) | Mar 2007 | Evaluates the program's functional and performance requirements ensuring proper formulation and correlation with Agency, and HEOMD's strategic objectives; assesses the credibility of the program's estimated budget and schedule | Program cleared to proceed to next phase | N/A |
| SDR | SRB | Aug 2007 | Evaluates proposed program requirements and architecture; allocation of requirements to initial projects; assesses the adequacy of project pre-formulation efforts; determines if maturity of the program's definition and plans are sufficient to begin implementation. | Program cleared to proceed to next phase. | N/A |

# CREW VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| PDR | SRB | Sep 2009 | Evaluates completeness and consistency of the program's preliminary design, including its projects, is meeting all requirements with appropriate margins, acceptable risk, and within cost and schedule constraints; and determines the program's readiness to proceed with the detailed design phase. | Program cleared to proceed to next phase. | N/A |
| Resynchronization Review | SRB | Jul 2012 | The review realign the program's preliminary design to the requirements of Exploration system development. NASA policies allow changes to a program's management agreement in response to internal and external events. An amendment to the decision memorandum signed at the KDP-B review held before PDR if a significant divergence occurs. | Program cleared to proceed to next phase. | N/A |

# CREW VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Delta PDR | SRB | Aug 2014 | Updates the program's preliminary design; ensures completeness and consistency; determines the program's readiness to proceed with the detailed design phase. | Program cleared to proceed to next phase. | N/A |
| CDR | SRB | Oct 2015 | This review evaluates the integrity of the program's integrated design. This includes its projects and ground systems, its ability to meet mission requirements with appropriate margins and acceptable risk, planned within cost and schedule constraints; determines if the integrated design is appropriately mature to continue with the final design and fabrication phase for EM-1. | Program cleared to proceed to next phase. | N/A |

# SPACE LAUNCH SYSTEM

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Launch Vehicle Development | 1646.6 | 1950 | **1262.8** | 1295 | 1419.7 | 1431.5 | 1454.6 |
| SLS Program Integration and Support | 32 | 50 | **47.5** | 66.5 | 65 | 68.1 | 69.6 |
| **Total in FY17 Budget Structure** | **1678.6** | **2000.0** | **1310.3** | **1361.5** | **1484.7** | **1499.6** | **1524.2** |
| Programmatic CoF in CECR Account | 67.9 | 10.0 | **8.8** | 9.0 | 9.2 | 9.4 | 9.6 |
| Exploration Ground Systems | 342.8 | 410 | **429.4** | 441.2 | 453 | 457.5 | 464.7 |
| **Total in FY12 Budget Structure** | **2089.3** | **2420** | **1748.5** | **1811.7** | **1946.9** | **1966.5** | **1998.5** |
| Change from FY 2015 | | | **-671.5** | | | | |
| Percentage change from FY 2015 | | | **-27.7%** | | | | |

*FY 2017 includes a column for PBR 2017 which includes both Discretionary and the Mandatory Funding Initiative for R&D.*

**NASA's countdown to deep space continued with a series of tests during 2015 of its SLS RS-25 rocket engine to collect engine performance data at NASA's Stennis Space Center (SSC) near Bay St. Louis, Mississippi. Operators on the A-1 Test Stand at SSC are conducting the test series to qualify an all-new engine controller and put the upgraded former space shuttle main engines through the rigorous temperature and pressure conditions they will experience during a SLS mission)**

As NASA seeks to expand the boundaries of human space exploration, SLS is preparing to carry humans and equipment farther into deep space than ever before.

SLS is a critical capability for exploring the solar system and continuing U.S. leadership in science, technology, and exploration for decades to come. The vehicle's capabilities will evolve using a block upgrade approach, driven by near- and long-term exploration mission requirements. Initially, SLS has the capability to carry over 70 metric tons to low Earth orbit and nearly 30 metric tons to the exploration proving ground near the Moon. Follow-on upgrades, including an advanced EUS will improve vehicle lift performance to 105 metric tons to low-Earth orbit and 40 metric tons to the exploration proving ground, significantly increasing mission capability. Ultimately, SLS will evolve to carry over 130 metric tons to low Earth orbit. NASA has begun preliminary planning for the Exploration Upper Stage (EUS), which leverages technology investments made by the Space Technology Mission Directorate (STMD) in areas such as cryogenic fluid management and advanced composites. This close coordination demonstrated between STMD and HEOMD will serve as the foundation for future exploration technologies and capabilities needed to explore Mars in the 2030s.

# SPACE LAUNCH SYSTEM

NASA is leveraging a half-century of experience with launch vehicles like Saturn and Space Shuttle, along with advancements in technology and manufacturing practices, to build and plan for operating SLS at less cost and risk than Saturn and the Space Shuttle. For instance, advances are allowing NASA to produce the first SLS boosters at about two-thirds the cost of the less-powerful Space Shuttle motors, and the core stage needs only half the weld manufacturing labor of the Space Shuttle external tank. The Agency will continue to identify and implement affordability strategies to ensure that SLS remains a core, sustainable exploration capability for decades to come.

Over the next 20 years, crewed missions using SLS and the Orion crew vehicle will be able to take advantage of the solar system's asteroids and the proving ground of space near the Moon to prepare for the enormous challenges of exploring Mars. These near-term SLS and Orion missions will support the Agency's mission to find, capture, redirect, and study a near Earth asteroid.

For further programmatic information, go to: http://www.nasa.gov/exploration/systems/sls/index.html.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Mandatory Budget Authority** | -- | -- | 80.4 | -- | -- | -- | -- |

SLS is supported in part with mandatory funding

# Program Elements

## SLS PROGRAM INTEGRATION AND SUPPORT

SLS program integration and support activities manage the Orion and EGS program interfaces. This effort is critical to ensuring that SLS systems performance meets technical and safety specifications, and supports the programmatic assessments that are key to achieving integrated technical, cost, and schedule management. In addition, the SLS integration effort is vital to managing interfaces with other HEOMD activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. To align upcoming HEOMD exploration and technology activities, some associated cross-cutting studies and initiatives that had been conducted in other programs have now been realigned to AES, enabling effective coordination between research and technology capabilities required to support robotic, extravehicular activities, ARM, and future exploration missions. Coordination and timely integration across the three programs enables the Agency to avoid potential design overlaps, schedule disconnects, and cost issues.

## LAUNCH VEHICLE DEVELOPMENT

See Launch Vehicle Development section.

# LAUNCH VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Prior | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 | BTC | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Formulation | 2674.0 | 0.0 | 0.0 | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2674.0 |
| Development/Implementation | 1579.2 | 1540.1 | 1721.7 | **1154.6** | 1025.8 | 0.0 | 0.0 | 0.0 | 0.0 | 7021.4 |
| Operations/Close-out | 0.0 | 0.0 | 0.0 | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **2016 MPAR LCC Estimate** | **4253.2** | **1540.1** | **1721.7** | **1154.6** | **1025.8** | **0.0** | **0.0** | **0.0** | **0.0** | **9695.4** |
| **Total Budget** | **3969.3** | **1646.6** | **1950.0** | **1262.8** | **1295.0** | **1419.7** | **1431.5** | **1454.6** | **0.0** | **14429.4** |
| Change from FY 2016 | | | | **-687.2** | | | | | | |
| Percentage change from FY 2016 | | | | **-35.2%** | | | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

*2016 MPAR LCC estimate includes funding from all appropriations, Exploration and Construction and Environmental Compliance and Restoration. Budget line reflects funding from the Exploration appropriation only.*

# LAUNCH VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

**At the Promontory, Utah test facility of Orbital ATK, the booster for NASA's SLS rocket fired for a two-minute test on March 11, 2015. NASA and Orbital ATK have successfully completed three full-scale development test firings of the five-segment solid rocket motor, as well as the important booster CDR)**

## PROJECT PURPOSE

As NASA expands its focus for human space flight to destinations across the solar system, the Launch Vehicle Development project will enable deep space exploration with the SLS launch vehicle. This heavy-lift rocket will have a lift capability more than two and one-half times any launch vehicle currently in operation. For the first time since the Apollo program, American astronauts will be able to explore space beyond low Earth orbit.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## PROJECT PARAMETERS

Launch Vehicle Development will work to achieve cost, schedule, and performance goals by utilizing hardware designed for previous programs, including Space Shuttle main engines, five-segment solid rocket boosters, and an interim cryogenic propulsion stage derivative from the Delta IV cryogenic second stage. The program benefits from NASA's half-century of experience with liquid oxygen and liquid hydrogen heavy-lift vehicles, large solid rocket motors, and advances in technology and manufacturing practices.

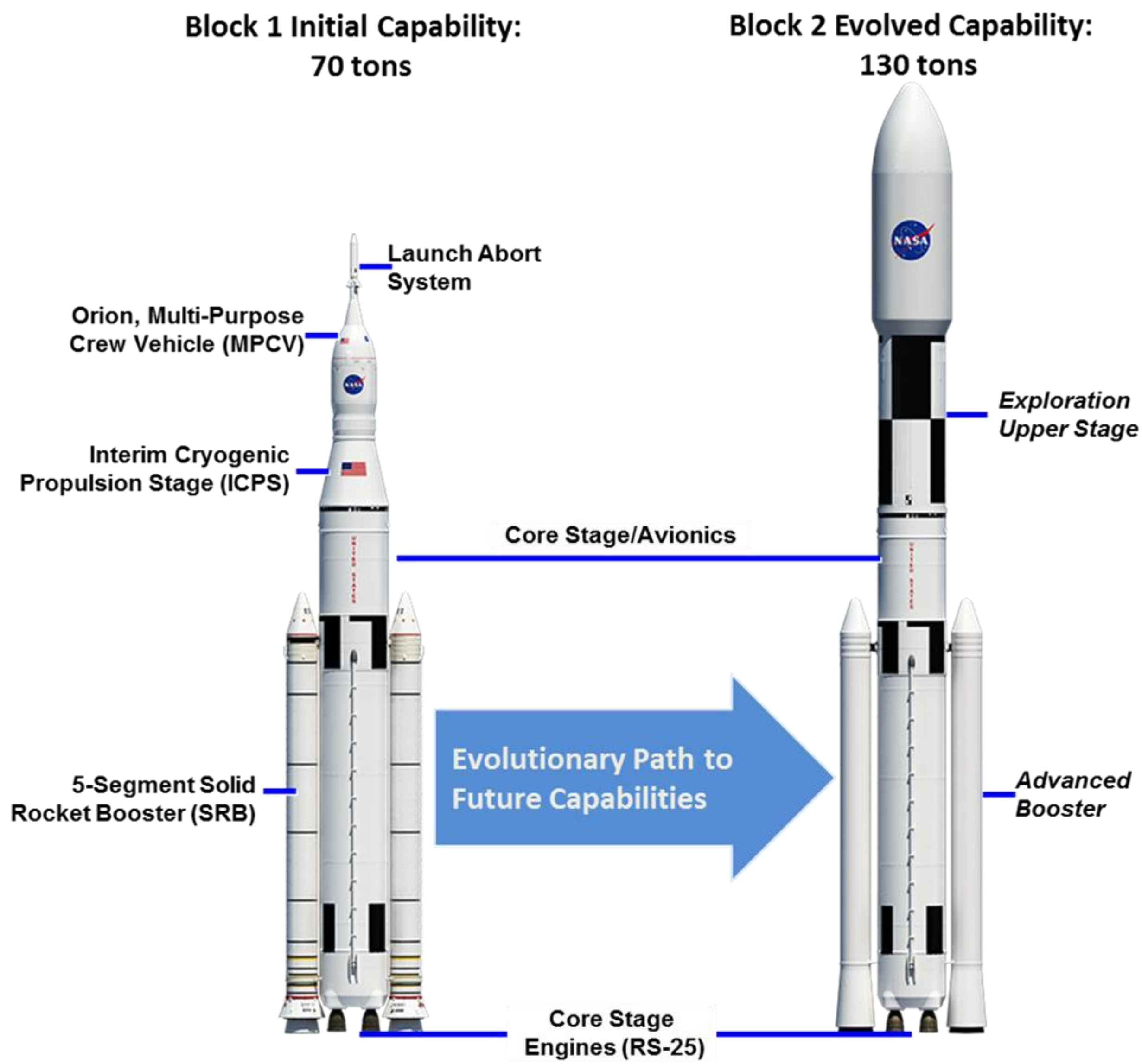
SLS vehicle design will be flexible and evolvable, based on mission requirements. In an effort to achieve schedule and cost efficiencies, each evolution shares the same core stage to accommodate both crew and cargo requirements as needed. SLS will provide unique capabilities for human and robotic explorations beyond low Earth orbit, including travel to asteroids, Mars, and other destinations in the solar system.

Initially, SLS will achieve a 70-metric ton lift capability to low Earth orbit, and nearly 30 metric tons to an exploration proving ground near the Moon. Upgrades, including an advanced EUS, will improve vehicle lift performance to 105 metric tons to low Earth orbit and 40 metric tons to cis-lunar space, where NASA will demonstrate deep space technologies and hardware needed for future missions, independent of Earth. Ultimately, SLS will be evolved to carry over 130 metric tons to low Earth orbit.

NASA is conducting preliminary planning for the EUS, which leverages technology investments made by the STMD in areas such as cryogenic fluid management and advanced composites. This close coordination demonstrated between STMD and HEOMD will serve as the foundation for future exploration technologies and capabilities needed to explore Mars in the 2030s.

# LAUNCH VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
| --- | --- | --- |




## ACHIEVEMENTS IN FY 2015

SLS is on track to provide all EM-1 flight hardware to KSC and support EM-1 launch readiness of November 2018. In FY 2015, SLS completed assembly of the first flight configuration RS-25 engine and successfully conducted a series of RS-25 engine tests on the A-1 Test Stand at SSC. The primary objective of this test series was to demonstrate the RS-25 could perform under new SLS Core Stage flight profile conditions. The SLS Booster Qualification Motor-1 test at Orbital ATK fired successfully in March 2015. This is the first of two qualification motor tests qualifying the design for use on SLS. In the summer of 2015, SLS successfully completed its CDR. The purpose of the CDR is to evaluate the

# LAUNCH VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

integrity of project design and its ability to meet mission requirements with appropriate margins and acceptable risk. The review determines if the design is appropriately mature to continue with the final design and fabrication phase. SLS completed integration of avionics into the software integration test facility (SITF) allowing development testing of avionics to commence in a flight-like system. Construction of structural test article facilities at Marshall Space Flight Center (MSFC) continued. Significant progress has been made fabricating major parts of the core stage liquid hydrogen tank, liquid oxygen tank, intertank, forward skirt, and engine structure. SLS has made significant progress with the manufacturing and assembly of the launch vehicle stage adapter structural test article, ICPS structural test article, core stage qualification and flight components, and the booster thrust vector control assembly. Now that SLS is beyond a CDR-level of design maturity, the Program is progressing towards fabrication, qualification, and assembly along with transitioning to a focus on verification to support design certification.

## WORK IN PROGRESS IN FY 2016

SLS will conduct SLS Booster Qualification Motor-2 test at Orbital ATK. SLS will complete fabrication on the Launch Vehicle Stage Adapter structural test article, ICPS structural test article, and Orion Stage Adapter structural test article. SLS will complete testing of EM-1 flight RS-25 engines.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

SLS will complete production of the EM-1 ICPS and will deliver the unit to KSC along with the Booster Solid Rocket Motor Aft Segment, Booster Aft Exit Cone and Skirts, Booster Solid Rocket Motor Forward Segments, and Booster Solid Rocket Motor Center Segments to begin final assembly. The RS-25 flight engines will deliver to MAF for integration into the core stage. Additionally, qualification testing of the Core Stage structural test articles will begin.

## SCHEDULE COMMITMENTS/KEY MILESTONES

| Milestone | Confirmation Baseline Date | FY 2017 PB Request |
|---|---|---|
| KDP-A | Nov 2011 | Nov 2011 |
| Formulation Authorization | May 2012 | May 2012 |
| SRR/SDR | May 2012 | May 2012 |
| KDP-B Agency Project Management Council (APMC) | Jul 2012 | Jul 2012 |
| PDR Board | Jun 2013 | Jun 2013 |
| KDP-C APMC | Jan 2014 | Jan 2014 |
| CDR Board | Jul 2015 | Jul 2015 |
| KDP-D APMC | Oct 2016 | Oct 2016 |

# LAUNCH VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

| Milestone | Confirmation Baseline Date | FY 2017 PB Request |
|---|---|---|
| Design Certification Review | Sep 2017 | Jan 2018 |
| EM-1 Launch Readiness | Nov 2018 | Nov 2018 |

## Development Cost and Schedule

| Base Year | Base Year Develop-ment Cost Estimate ($M) | JCL (%) | Current Year | Current Year Develop-ment Cost Estimate ($M) | Cost Change (%) | Key Milestone | Base Year Mileston e Data | Current Year Milestone Data | Milestone Change (mths) |
|---|---|---|---|---|---|---|---|---|---|
| 2013 | 7,021.4 | 70 | 2015 | 7,021.4 | -- | EM-1 Launch Readiness | Nov 2018 | Nov 2018 | -- |

*Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.*

## Development Cost Details

| Element | Base Year Development Cost Estimate ($M) | Current Year Development Cost Estimate ($M) | Change from Base Year Estimate ($M) |
|---|---|---|---|
| **TOTAL:** | **7,021.4** | **7021.4** | **-** |
| Stages Element | 3,138.7 | 3,600.00 | 461.30 |
| Liquid Engines Office | 1,198.3 | 500.00 | -698.30 |
| Booster Element | 1,090.3 | 1,100.00 | 9.70 |
| Other | 1,594.2 | 1,821.4 | 227.20 |

# LAUNCH VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

## Project Management & Commitments

| Element | Description | Provider Details | Change from Baseline |
|---|---|---|---|
| Booster | Responsible for development, testing, production, and support for the five-segment solid rocket motor to be used on initial capability flights | Provider: MSFC<br><br>Lead Center: MSFC<br><br>Performing Center(s): MSFC<br><br>Cost Share Partner(s): N/A | |
| Engines | Responsible for development and/or testing, production, and support for both core stage (RS-25) and upper stage liquid engines | Provider: MSFC<br><br>Lead Center: MSFC<br><br>Performing Center(s): MSFC and SSC<br><br>Cost Share Partner(s): N/A | |
| Stages | Responsible for development, testing, production, and support of hardware elements, including core and upper stages, liquid engine and avionics integration | Provider: MSFC<br><br>Lead Center: MSFC<br><br>Performing Center(s): MSFC, SSC, and KSC<br><br>Cost Share Partner(s): N/A | |
| Spacecraft Payloads and Integration | Responsible for development, testing, production, and support of hardware elements for integrating the Orion and payloads onto SLS, including the interim cryogenic propulsion stage, Orion stage adapter, launch vehicle stage adapter, and payload fairings | Provider: MSFC<br><br>Lead Center: MSFC<br><br>Performing Center(s): MSFC, LaRC, GRC, and KSC<br><br>Cost Share Partner(s): N/A | |

# LAUNCH VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

## Project Risks

| Risk Statement | Mitigation |
|---|---|
| If: For the SLS boosters, small voids seen between the motor propellant and booster liner in early qualification motor aft segments are not addressed,<br><br>Then: The delay in two booster qualification motor tests could affect the EM-1 launch readiness date of November 2018. | SLS has built several motor test articles and full process simulation segments to analyze the potential safety impacts of voids for both qualification and flight motors. Tests and analyses to date demonstrate that the program understands the complex chemical and manufacturing interactions between the new booster liner and propellant. Successfully validated the qualification motor 1 (QM-1) with a test firing in FY 2015. Rigorous X-ray inspections of QM-2 segments continue to demonstrate a lack of voids between the propellant and booster liner. Booster qualification tests continue to maintain schedule margin. |
| If: uncertainties which affect the ability to safely burn-off the hydrogen gas emitted by the Core Stage Engines prior to launch are not addressed,<br><br>Then: there is a possibility that an overpressure event in excess of the baseline environment may occur, which may have performance and safety impacts. | SLS has performed several analyses and field tests of the hydrogen burn-off igniter performance under several environmental conditions that bound the range of uncertainties including winds and water impingement. Analyses and test data indicate that a simple reconfiguration of the igniters can mitigate the risk. Risk remains open pending final analyses and implementation of the mitigation in the baseline design. |

## Acquisition Strategy

### MAJOR CONTRACTS/AWARDS

Procurement for SLS launch vehicle development meets the Agency's requirement to provide an affordable and evolvable vehicle within a schedule that supports various mission requirements. Procurements include use of existing assets to expedite development, as well as further development of technologies and future competitions for advanced systems and key technology areas, specific to SLS vehicle needs

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Boosters | Orbital ATK | Magna, UT |
| Core Stage Engine | Aerojet Rocketdyne | Desoto Park, CA |
| ICPS | Boeing Aerospace | Huntsville, AL |

# LAUNCH VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Stages | Boeing Aerospace | Huntsville, AL |

## INDEPENDENT REVIEWS

NASA established an SRB to perform the independent reviews of the Space Launch Vehicle project as required by NPR 7120.5.

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| PDR | SRB | Aug 2013 | The purpose of PDR is to evaluate the completeness/ consistency of the planning, technical, cost, and schedule baselines developed during formulation; assess compliance of the preliminary design with applicable requirements; and to determine if the project is sufficiently mature to begin Phase C. | The SRB evaluated the project and determined the project is sufficiently mature to begin Phase C. | N/A |

# LAUNCH VEHICLE DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| CDR | SRB | Jul 2015 | The purpose of CDR is to evaluate the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk within defined project constraints, including available resources. The review determines if the design is appropriately mature to continue with the final design and fabrication phase. | The SRB evaluated the project and determined the project is sufficiently mature to major manufacturing, assembly and integration. | N/A |
| DCR | SLS Independent Review Team | Jan 2018 | The purpose of the DCR is to certify the implemented design complies with applicable requirements and necessary verification activities are satisfactorily completed. | Certification of the SLS Block 1 design is completed. | N/A |

# EXPLORATION GROUND SYSTEMS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **342.8** | **410.0** | **429.4** | **441.2** | **453.0** | **457.5** | **464.7** |
| Change from FY 2016 | | | **19.4** | | | | |
| Percentage change from FY 2016 | | | **4.7%** | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding.  Additional details on the mandatory funding can be found in the Explanation of Changes section.*

**A view of the VAB at NASA's KSC in Florida. To the left is the mobile launcher that will be used to carry NASA's SLS rocket and Orion spacecraft to Launch Pad 39B for EM-1.**

The EGS program enables integration, processing, and launch of the SLS and Orion Crew Vehicle. EGS is making required facility and ground support equipment modifications at KSC to enable assembly, test, launch, and recovery of the SLS and Orion flight elements. EGS is also modernizing communication and control systems to support these activities. Upon completion, the KSC launch site will be able to provide a more flexible, affordable, and responsive national launch capability. The beneficiaries are current and future NASA programs including Orion, SLS, and additional customers such as U.S. government agencies and commercial industry.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

| (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Mandatory Budget Authority** | -- | -- | **26.2** | -- | -- | -- | -- |

EGS is in part funded with mandatory funding.

# EXPLORATION GROUND SYSTEMS

## Program Elements

### EGS PROGRAM INTEGRATION AND SUPPORT

EGS program integration and support activities manage the SLS and Orion program interfaces. This effort is critical to ensuring ground systems performance meets technical and safety specifications and supports the programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the EGS integration effort is vital to managing interfaces with other HEO activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across the three programs enables the Agency to avoid potential design overlaps, schedule disconnects, and cost issues.

### EXPLORATION GROUND SYSTEMS DEVELOPMENT

See the Exploration Ground Systems Development.

# EXPLORATION GROUND SYSTEMS DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Prior | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 | BTC | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Formulation | 965.8 | 0.0 | 0.0 | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 965.8 |
| Development/Implementation | 176.3 | 353.3 | 403.3 | **417.1** | 425.9 | 71.2 | 0.0 | 0.0 | 0.0 | 1847.1 |
| Operations/Close-out | 0.0 | 0.0 | 0.0 | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **2016 MPAR LCC Estimate** | **1142.1** | **353.3** | **403.3** | **417.1** | **425.9** | **71.2** | **0.0** | **0.0** | **0.0** | **2812.9** |
| **Total Budget** | **966.2** | **305.9** | **390.9** | **414.1** | **425.9** | **437.7** | **442.1** | **449.1** | **0.0** | **3831.8** |
| Change from FY 2016 | | | | **23.2** | | | | | | |
| Percentage change from FY 2016 | | | | **5.9%** | | | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. For projects in development, NASA's tentatively planned FY 2016 funding level is shown. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 reflects discretionary and mandatory funding. Additional details on the mandatory funding can be found in the Explanation of Changes section.*

*2016 MPAR LCC estimate includes funding from all appropriations, Exploration and Construction and Environmental Compliance and Restoration. Budget line reflects funding from the Exploration appropriation only.*

# EXPLORATION GROUND SYSTEMS DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

**A technician monitors the progress as NASA's crawler-transporter 2 moves slowly along the crawlerway back to the crawler park site after a test run to Launch Pad 39B at NASA's KSC in Florida. Upgrades to the crawler include 88 new roller bearings, 22 on each "truck" section, and a new jacking, equalizing and leveling system. In the background is the new mobile launcher.)**

## PROJECT PURPOSE

As NASA enters a new era in human space exploration, space operations at KSC are evolving to accommodate NASA's next-generation human space exploration vehicles. EGS is developing the ground systems infrastructure required to assemble, test, and launch SLS and Orion, along with the recovery of Orion.

For more programmatic information, go to http://go.nasa.gov/groundsystems.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## PROJECT PARAMETERS

EGS is modernizing and upgrading KSC ground systems and facilities required to integrate SLS and Orion, to move the integrated vehicle to the launch pad, and to launch it successfully into space. Many of the current ground systems and facilities date back to the Apollo era, so modernization is critical to the program's ability to assemble, test, launch, and recover SLS and Orion elements. For the Exploration Missions, EM-1 and EM-2, the EGS team is developing procedures and protocols to process the spacecraft, rocket stages, and launch abort system before assembly into one vehicle. Additional work required to launch astronauts into space includes modifying the mobile launcher and crawler-transporters; preparing Launch Complex-39B, rocket launch site at KSC, modernizing computers, tracking systems, and other networks.

## ACHIEVEMENTS IN FY 2015

EGS successfully completed the landing and recovery operations of the Orion crew module on December 5, 2014, marking the end of the EFT-1. Following splashdown in the Pacific Ocean, after having traveled two orbits around the Earth to test systems critical to crew safety, EGS sent Orion on a 2,700-mile cross-country trip back to KSC for post-mission analysis.

The program began installing ground support equipment and completing structural and facility modifications on the mobile launcher. In the VAB, adjustable high-bay platform construction continued, providing access levels required for SLS vehicle processing. At LC-39B, EGS began Pad B flame trench/flame deflector construction and completed modifications for infrastructure and propellant and gas systems... The flame trench brick, which date back to the Apollo program, installed during construction of the pad in the 1960s. A new flame deflector is being designed that will support NASA's SLS rocket and a variety of other commercial launch vehicles.

# EXPLORATION GROUND SYSTEMS DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

EGS continued installing and upgrading software to support end-to-end spaceport command and control system applications and displays required in ground processing facilities. Life extension modifications for the crawler transporter continued in order to complete roller bearings, jacking, equalizing, and leveling (JEL) cylinder replacement. These modifications are necessary for future NASA space exploration missions beyond low Earth Orbit, beginning with EM-1 and EM-2.

## WORK IN PROGRESS IN FY 2016

Major program readiness will near its final preparation phase for the EM-1 launch. The program will complete structural and facility modifications on the mobile launcher, and finish installing ground support equipment. EGS will conduct Launch Equipment Test Facility umbilical testing, complete installation of the crawler transporter JEL cylinder, and complete Multi-Payload Processing Facility upgrades. Command, control, and communications systems software and displays that support end-to-end spaceport applications are preparing to support launch. In the VAB, EGS will complete adjustable high-bay platform construction, and utilize in support of SLS stacking and integration for EM-1. At LC-39B, EGS will complete flame trench/flame deflector, as well as modifications for infrastructure and propellant and gas systems in preparation for launch. The program completed CDR Board in December 2015 to evaluate ground systems design integrity, and its ability to meet mission requirements within available resources with appropriate margins and acceptable risk.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

EGS will complete detailed design, production, testing, verification and validation (V&V) of ground processing facilities. The activities include not only developing necessary ground systems, they also allow for refurbishing and upgrading infrastructure and facilities to meet future demand. Plans also include completion of the Flame trench/deflector and Pad B construction. EGS will complete the Spaceport Command and Control System (SCCS) 4.1 development and validation, and the Mobile Launcher (ML) ground support equipment (GSE) installation and umbilical installation contract. There are three underway recovery tests planned in support of EM-1 beginning in November 2016. The tests will allow NASA and the Navy to continue to demonstrate and evaluate the recovery processes, procedures, and hardware in the real world open ocean environment before committing to conducting actual recovery operations for EMs. Finally, the VAB and Pad B will be ready for the ML.

Based on direction contained in the Consolidation Appropriations Act 2016, (P.L. 114-113), EGS is also exploring changes required to support SLS upgrades for EM-2 to SCCS, the ML and additional liquid hydrogen capacity at the pad.

## SCHEDULE COMMITMENTS/KEY MILESTONES

| Milestone | Confirmation Baseline Date | FY 2017 PB Request |
|---|---|---|
| KDP-A | Feb 2012 | Feb 2012 |

# EXPLORATION GROUND SYSTEMS DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

| Milestone | Confirmation Baseline Date | FY 2017 PB Request |
|---|---|---|
| Formulation Authorization | Apr 2012 | Apr 2012 |
| SRR/SDR | Aug 2012 | Aug 2012 |
| KDP-B APMC | Nov 2012 | Nov 2012 |
| PDR Board | Mar 2014 | Mar 2014 |
| KDP-C APMC | May 2014 | May 2014 |
| CDR Board | Dec 2015 | Dec 2015 |
| KDP-D | Under Review | Under Review |
| EM-1 Launch Readiness | Nov 2018 | Nov 2018 |

## Development Cost and Schedule

| Base Year | Base Year Develop-ment Cost Estimate ($M) | JCL (%) | Current Year | Current Year Develop-ment Cost Estimate ($M) | Cost Change (%) | Key Milestone | Base Year Milestone Data | Current Year Milestone Data | Milestone Change (mths) |
|---|---|---|---|---|---|---|---|---|---|
| 2015 | 1,843.5 | 80 | 2016 | 1,847.2 | .2 | EM-1 Readi-ness | Nov 2018 | Nov 2018 | N/A |

*Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.*

## Development Cost Details

# EXPLORATION GROUND SYSTEMS DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

| Element | Base Year Development Cost Estimate ($M) | Current Year Development Cost Estimate ($M) | Change from Base Year Estimate ($M) |
|---|---|---|---|
| **TOTAL:** | **1843.5** | **1,847.2** | **3.7** |
| ML | 213.1 | 226.9 | 13.8 |
| LC-39B Pad | 77.5 | 52.2 | -25.3 |
| VAB | 92.7 | 76.2 | -16.5 |
| Command, Control, and Communications | 198.0 | 248.6 | 50.6 |
| Offline Processing and Infrastructure | 110.2 | 108.6 | -1.6 |
| Other | 1,152.0 | 1,134.7 | -17.3 |

**Other includes Crawler Transporter, Launch Equipment Test Facility, Integrated Operations, Program Management, Logistics, S&MA, and SE&I*

# EXPLORATION GROUND SYSTEMS DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

## Project Management & Commitments

The Ground Systems Development and Operations Program Office (GSDO) manage EGS and 21st Century Space Launch Complex (21CSLC) activities. GSDO balances customer requirements among SLS, Orion, and other Government and commercial users to provide synergy between EGS and 21CSLC. EGS is developing ground systems infrastructure necessary to assemble, test, launch, and recover SLS and Orion elements, while 21CSLC is focusing on enabling NASA facilities to support multiple users. In FY 2016, EGS transitioned the program to a new Mission Management Model to develop ground system and processes, and launch flight hardware by aligning roles and responsibilities, synergizing functions, and simplifying interfaces.

| Element | Description | Provider Details | Change from Baseline |
|---|---|---|---|
| Ground Systems Implementation (GSI) | GSI is Responsible for design, development, build, hardware/software integration, verification and facility systems, and GSE. | Provider: KSC<br>Lead Center: KSC<br>Performing Center(s): ARC<br>Cost Share Partner(s): N/A | N/A |
| Operating Planning and Execution (OP&E) | OP&E is Responsible for conducting overall planning and execution of both flight hardware and ground systems processing activities. | Provider: KSC<br>Lead Center: KSC<br>Performing Center(s): N/A<br>Cost Share Partner(s): N/A | N/A |
| Command, Control, Communication (C3) | C3 is Responsible for development, operation, and sustainment of End-to-End Command and Control and Communications services. | Provider: KSC<br>Lead Center: KSC<br>Performing Center(s): N/A<br>Cost Share Partner(s): N/A | N/A |
| Mission Management Team (MMT) | MMT includes project management, safety and mission assurance, logistics, systems engineering, utilities and facility operations and maintenance. | Provider: KSC<br>Lead Center: KSC<br>Performing Center(s): N/A<br>Cost Share Partner(s): N/A | N/A |

# EXPLORATION GROUND SYSTEMS DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

## Project Risks

| Risk Statement | Mitigation |
|---|---|
| If: Insufficient time and budget is allotted to the SCCS 4 software development project,<br>Then: there is a possibility SCCS 4 will not be ready for use within the baseline E2E-C2 schedule to support SCCS 4 validation activities, operational needs and programmatic scheduled testing. | GSDO is hiring additional workforce to maintain schedule and developing process improvements with contracting company. |
| If: There is insufficient time to perform all V&V activities,<br>Then: there is a possibility of a schedule delay to the GSDO Operations Readiness Date. | GSDO formed an integrated team to perform a scrub of the ML V&V/Multi-Element V&V Integrated Master Schedule to obtain a credible V&V schedule. |
| If: the Ground Flight Application Software Team (GFAST) internal/external dependencies on GSE subsystems, SCCS, Models and Emulators, SLS, Orion and ICPS to provide requirements, data products and hardware are not within the currently defined GFAST schedule,<br>Then: there is the possibility GFAST will not be ready to perform integrated processing with flight hardware and GSE in the VAB/Pad and MPPF in time to meet Cross-Program objective and schedules while remaining within allocated budgets. | GFAST developed tools that reduced development time by 50 percent, minimize the impact of limited Design, Development and Evaluation asset availability, and expedite code development. Team also refined dependency needs across each GFAST drop/team and started negotiations with Orion/SLS/ICPS for Flight Software, Operations and Maintenance Requirements and Specifications, and Launch Commit Criteria Products. |

## Acquisition Strategy

To retain flexibility and maximize affordability, GSDO serves as its own prime contractor for EGS development activities. EGS executes SLS and Orion ground infrastructure and processing requirements by leveraging center and programmatic contracts. For more routine work, EGS also uses pre-qualified Indefinite-delivery, Indefinite-quantity contractors while exercising full and open competition for larger or more specialized projects, such as the mobile launcher structural and facility systems construction contract, and associated GSE fabrication firm-fixed-price contracts. A fixed-price contracting approach is the first choice whenever possible, as it provides maximum incentive for contractors to control costs, since they are subject to any losses incurred. In addition, it imposes a minimal administrative burden upon the contracting parties.

# EXPLORATION GROUND SYSTEMS DEVELOPMENT

| Formulation | Development | Operations |
|---|---|---|

## MAJOR CONTRACTS/AWARDS

EGS development activities will encompass projects of varying content and size. EGS does not have a prime contract, the project uses the Center's institutional contracts to execute the development, engineering, construction and programmatic activities. If the project size or scope falls outside existing center capabilities, then a competitively bid firm-fixed-price contract will be used. EGS contracts are below.

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Mobile Launcher Structural and Facility Support Modification Contract | J.P. Donovan Construction, Inc. | KSC |
| VAB High Bay Platform Construction | Hensel Phelps Construction, Inc. | KSC |

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| All | SRB | Nov 2012 | Provides independent assessment of program technical plan, cost estimates, schedules, and risks at KDP-B | Program cleared to proceed to next phase | N/A |
| PDR | SRB | Mar 2014 | Evaluates completeness and consistency of program preliminary design; determines readiness to proceed with detailed design phase | Program cleared to proceed to next phase | N/A |
| CDR | SRB | Mar 2016 | Demonstrates that program design is mature; supports full-scale fabrication, assembly, integration, and test; and meets overall performance requirements within cost and schedule constraints | | TBD |

# HUMAN RESEARCH PROGRAM

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **142.0** | **--** | **153.3** | **178.2** | **178.2** | **180.0** | **182.8** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 includes a column for PBR 2017 which includes both Discretionary and the Mandatory Funding Initiative for R&D.*

**HRP researchers are gathering reams of genomic, molecular, physiological, and other data on Scott Kelly (right) as he continues his one-year ISS mission and comparing it to his Earth-dwelling identical twin, retired astronaut Mark Kelly (left).**

Sending astronauts into space involves a multitude of complicated systems, but perhaps the most complex is the human system. While NASA has amassed more than 50 years of crew experience in low Earth orbit, researchers continue to unravel the mysteries of how the human body responds to the harsh environment of space. HRP is responsible for understanding and mitigating the highest risks to astronaut health and performance to ensure that crews remain healthy and productive during long-duration missions beyond low Earth orbit.

As NASA prepares to conduct crewed missions in cis-lunar space using SLS and Orion, and eventually at other locations, including Mars, HRP is developing the scientific and technological expertise to send humans into deep space for longer durations. Coordinating with the National Academies, National Council on Radiation Protection, and other external partners, HRP continues to deliver products and strategies to protect crew health and safety, and maximize productivity while living and working in space. Experiments on the ISS, as well as in ground-based analog environments and laboratories, expand research and technology development for protecting the human system in multiple ways. Investigations regarding space radiation protection, deep space habitat systems, psychological support systems, innovative medical technologies, and new exploration capabilities, such as food systems, vehicle and space suit requirements, and validated countermeasure systems that ensure crew health during all phases of flight, are continuing to evolve.

Space radiation poses significant health risks for crewmembers, including the possibility of developing cancer later in life, radiation sickness during the mission, and post mission effects on the nervous and cardiovascular systems. HRP is working with the AES, Crew Health and Safety, and Orion teams on both in-mission and post-mission radiation countermeasures to minimize exposures and provide radiation protection. The collaborative effort with AES involves developing advanced radiation shielding technologies, designing standards and providing the requirements for real-time radiation alert systems, optimal mission architectures, biomedical radiation sensitivity screening, as well as incorporating post-mission health surveillance to ensure that crewmembers can safely live and work in space without exceeding acceptable radiation health risks.

In collaboration with other federal agencies, such as the Department of Defense, the Department of Energy, and the National Institutes of Health, HRP supports space human system research to increase understanding of the effects of microgravity on human physiological systems. This knowledge is critical to NASA's plans for long-duration human space missions beyond low Earth orbit. In addition, as is the case with many space-based medical investigations, this research may also lead to significant advancements in treating patients on Earth.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None

## ACHIEVEMENTS IN FY 2015

FY 2015 marked the launch of astronaut Scott Kelly and cosmonaut Mikhail Kornienko to the ISS, where they are living for an entire year in a joint U.S./Russian mission—the longest mission ever assigned to a U.S. astronaut. Integral to the ISS one-year mission, HRP partnered with its Russian counterparts from the Institute for Biomedical Problems in Moscow to implement a biomedical research campaign. This campaign will yield valuable information regarding medical countermeasures for bone, muscle, and cardiovascular deconditioning; behavioral health and performance; and medical operation challenges people on Earth may experience as well as future explorers as they venture to an asteroid, Mars, and beyond. It rejuvenated a strong collaborative international program that will leverage global assets toward solving complicated crew health and performance concerns for future exploration missions.

In conjunction with the ISS one-year mission, HRP also undertook the identical twins study, where astronaut Scott Kelly is spending 12 months in orbit on the ISS, while retired astronaut Mark Kelly remains on Earth. Scientists will look at the way genes and proteins in the cells in Scott Kelly are regulated due to spaceflight, and they will compare those results to the proteins and cells in his twin, Mark, to gain significant insight into the real-time genetic effects of spaceflight and its impacts on the human body at the molecular level. To prepare for these studies, the Agency developed policies for the proper use of astronaut genetic information. This has opened the door for HRP researchers to take advantage of the private sector revolution in precision medicine, while continuing to protect for crew health and performance, during future exploration missions.

HRP and the National Space Biomedical Research Institute (NSBRI) selected 26 proposals, out of 178 received, to investigate questions about astronaut health and performance on future deep space exploration missions. The proposals are from 23 institutions in 11 states, and will receive a total of about approximately $13.3 million during the performance period. Researchers will be investigating the impact of the space environment on various aspects of astronaut health, including visual impairment, behavioral health, bone loss, cardiovascular alterations, human factors and performance, neurobehavioral and psychosocial factors, sensorimotor adaptation and the development and application of smart medical systems and technologies. All of the selected research will contribute towards NASA's future missions beyond low Earth orbit and on to Mars.

In FY 2015, HRP also conducted approximately 18 space biomedical research investigations during each ISS mission increment, completed four flight investigations, and initiated nine new research investigations. This included an ongoing microbiome study to investigate the variety of microorganisms on, in, and around astronauts during space flight missions. The human body hosts millions of tiny organisms called microbes that play a key role in human health and it is important to understand the changes to this microbial population during long-duration space exploration. By sampling an astronaut's microbiome on Earth and in space, researchers hope to define the signatures of human response to a variety of relevant aspects of space travel. Potential applications to human health on Earth include early detection of diseases, alterations in metabolic function, and immune system deficiency.

## WORK IN PROGRESS IN FY 2016

HRP will conclude data collection from the one-year joint U.S./Russian ISS mission. This collection of data will provide NASA a first look into the effects of longer mission durations on ocular health, immune and cardiovascular systems, cognitive performance testing, and countermeasure effectiveness against bone and muscle loss. Findings from the identical twins' studies will also be concluding and this data will provide unprecedented information regarding the effects of space flight on the entire complement of biomolecules, such as proteins (proteomics), genes (genomics), etc. Such data potentially provides novel approaches to protecting the health and performance of crews during Mars missions and other exploration missions beyond low Earth orbit.

HRP researchers plan to conduct approximately 16 space biomedical research investigations during each ISS mission increment, complete five flight investigations, and initiate one new research investigation. These investigations will include work associated with both the one-year and six-month mission crews. Studies to mitigate the risk of long-duration space flight include a lighting countermeasure to help ISS crewmembers improve sleep and enhance performance; functional immune alterations; a tool to monitor crew medication usage, symptoms, and adverse effects during missions; and research on the altered distribution of fluid within the bodies of astronauts. This fluid research may prove to be significant to understanding visual impairments and intracranial pressure experienced by several crew members upon return from long duration missions. For example, during the ISS one-year mission, liters of fluid—or about a bottle of soda—will have shifted out of Scott Kelly's legs and toward his head. Earth applications may then also become available as more advanced imaging techniques are used to assess vision problems and develop ways to prevent them.

HRP will implement multiple studies on teamwork in spaceflight analog environments, with efforts heavily devoted to NASA's Human Exploration Research Analog (HERA). The HERA facility provides an environment in which spaceflight mission simulations can be conducted with high levels of experimental control. HRP is planning to implement four 30-day missions in the HERA: Teamwork studies include monitoring technologies; examining the effects of communication delay on performance; investigating team cohesion, cooperation, and resilience over time; and evaluating the effectiveness of team training countermeasures on mitigating potential behavioral or performance decrements.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

HRP will re-compete its external institute cooperative agreement for the first time in 20 years. The new initiative, public-private partnership -Translational Research Institute, will lead a national effort in translating cutting-edge emerging terrestrial biomedical research and technology development into applied space flight human risk mitigation strategies for exploration missions. The institute will solicit and select innovative multidisciplinary teams whose products have potential to significantly reduce NASA human health and performance risks during space exploration missions by "translating" research into application by increasing the exchange of information between the biomedical research community and the human spaceflight medical community.

HRP will initiate joint NASA/National Science Foundation Antarctic analog studies to support behavioral health and performance research. Working with the National Science Foundation Polar Program, HRP will integrate behavioral health and performance research studies into the Antarctic winter-over campaign sites that serve as operational analogs by providing long duration, isolation, confinement, and controlled conditions for research. Factors ranging from sleep loss and anxiety to communication difficulties and team dynamics can affect the health, safety, and productivity of crewmembers. Research in these areas could prove beneficial to people living and working under similar conditions on Earth.

Currently, no established methods exist to collect near real-time human factors and habitability data during space flight missions. Human factors and habitability data are instead acquired at the end of missions during post-flight crew debriefs. These debriefs occur weeks or often longer after events have occurred, which forces a significant reliance on incomplete human memory. In 2017 HRP plans to deliver a real-time crew performance assessment tool, which should prove very useful in gathering current data in the near-term as well as for applying to the designs of next generation spacecraft and habitats.

A potential mission-threatening medical event in astronauts could be from acute cardiovascular disease. The current risk prediction models are not optimized for predicting heart failure or atrial fibrillation and other cardiac arrhythmias during spaceflight. Therefore, HRP is working with biomedical and aerospace medicine researchers to enhance the spaceflight cardiovascular disease risk prediction tool to be delivered in FY 2017.

NASA will also begin joint NASA/German Aerospace Center (DLR) analog studies to support human health countermeasures, exploration medical and behavioral health and performance research. Working with the DLR Space Agency and the DLR Institute for Aerospace Medicine, NASA will integrate these studies into HERA missions, and DLR will integrate NASA studies into its envihab medical research facility bed rest campaigns.

## Program Elements

### EXPLORATION MEDICAL CAPABILITY

As NASA makes plans to extend human exploration beyond low Earth orbit, identifying and testing next-generation medical care and crew health maintenance technologies is vital. Health care options evolve based on experience, anticipated needs, and input from flight surgeons and crew offices. Crews will not be able to rely on real-time conversations with Earth-based medical experts in the future due to communication lag-time associated with the distance between Earth and Mars. Therefore, crew and relevant systems must be able to facilitate autonomous medical care operations. Teams in this area draft requirements for medical equipment and clinical care, develop remote medical technologies, and assess medical requirements unique to long-duration space missions.

# HUMAN RESEARCH PROGRAM

## HUMAN HEALTH COUNTERMEASURES

Countermeasures are the procedures, medications, devices, and other strategies that offset the impacts of spaceflight stressors (e.g., low gravity, high radiation, etc.) and help keep astronauts healthy and productive during space travel and after their return to Earth. Researchers provide biomedical expertise; they are responsible for understanding the normal physiologic effects of space flight, and then developing countermeasures to those with harmful effects on human health and performance. These experts define health and medical standards, validate human health prescriptions and exercise system requirements, develop injury and sickness prevention standards, integrate and validate physiological countermeasures, and establish criteria for NASA fitness for duty, as well as crew selection and performance standards.

## BEHAVIORAL HEALTH AND PERFORMANCE

Just as the space environment poses physical risks to crewmembers, the unique stresses and challenges of space flight can affect cognitive and mental performance. These researchers assess the impact of space travel on human behavioral health, and develop interventions and countermeasures to ensure optimal health and performance. Experts in this area make extensive use of analogs, which are experimental environments created to simulate certain aspects of space travel. By duplicating space conditions, such as altered day and night cycles, heavy workloads, social isolation, and close living quarters, scientists gain insight into the impact of these circumstances on human behavior and performance. They then work to develop countermeasures, equipment, and other interventions to minimize these risks.

## SPACE HUMAN FACTORS AND HABITABILITY

Crew performance and well-being is affected by where they live, what they eat, and even what they wear. Considering external factors is essential when designing a spacecraft, habitat, or spacesuit. Human factors experts develop new equipment, procedures, and technologies designed to make the space environment more livable. Food scientists work to create nutritious and palatable meals that can withstand the rigors of space flight, are simple to prepare, and generate minimal waste. Other studies necessary for living and working in space include determining impacts and limits of environmental factors, such as chemicals, bacteria, fungi, and dust from the Moon and Mars.

## SPACE RADIATION

As NASA expands human presence through the solar system, it is critical that crews are able to safely live and work in a space radiation environment without exceeding exposure limits. Space radiation researchers determine standards for health and habitability, and define requirements for radiation protection. They also develop tools to assess and predict risks due to space radiation exposure, and strategies to mitigate exposure effects. The deep space radiation environment is far different from that on Earth or in low Earth orbit. Thus, NASA and the Department of Energy have partnered on a facility at Brookhaven National Laboratory in New York to simulate the deep space radiation environment, which researchers use to help understand its biological effects.

# HUMAN RESEARCH PROGRAM

## ISS MEDICAL PROJECTS

The ISS provides a unique testbed for HRP activities. The medical projects team plans, integrates, and implements approved biomedical flight experiments on the ISS, as well as research studies that use ground experiments to accomplish program objectives. This includes pre- and post-flight activities, coordinating flight or ground resources with our international partners, maintaining ISS biomedical research racks and flight hardware, and developing crew training for both flight and ground investigations. Teams also operate a telescience support center, which provides real-time support and data services to all HRP flight experiments. Strong interfaces with external implementing organizations, such as the ISS payloads office, analog coordination offices, and international partners, are critical to maintaining a robust research program. This group is also responsible for operating the HERA analog facility at NASA-JSC and arranging access to other analog facilities required by HRP researchers, including National Science Foundation Antarctic facilities, other national isolation analogs, and international partner facilities in Germany and Russia.

## Program Schedule

| Date | Significant Event |
|---|---|
| Oct 2016 | Start Translation Research Institute Cooperative Agreement |
| Feb 2017 | Deliver Real-Time Crew Performance Assessment Tool |
| Feb 2017 | 2017 HRP Investigators' Workshop |
| Mar 2017 | Release 2017 NASA Research Announcement (NRA) in Space Radiation |
| Apr 2017 | Deliver Validation Study on Real-Time Neurocognitive Assessment Toolkit |
| May 2017 | 2016 Human Exploration Research Opportunity NRA Selections |
| May 2017 | Galactic Cosmic Ray (GCR) Simulator Commissioning |
| Jun 2017 | Complete Mission X: Train Like an Astronaut Fitness Challenge |
| Jun 2017 | Deliver Cardiovascular Risk Prediction Tool |
| Jul 2017 | Complete Study on Medical Outcome Metrics to Optimize Training |
| Jul 2017 | Deliver In-Mission Crew Training Tool for Long-Duration Spaceflight |
| Aug 2017 | Deliver Report on Virtual Reality Communication Software Demonstration |
| Aug 2017 | Release 2017 Human Exploration Research Opportunity NRA |
| Sep 2017 | 2017 NRA in Space Radiation Selections |
| Sep 2017 | Computational Model for Spacecraft/Habitat Volume |

# ADVANCED EXPLORATION SYSTEMS

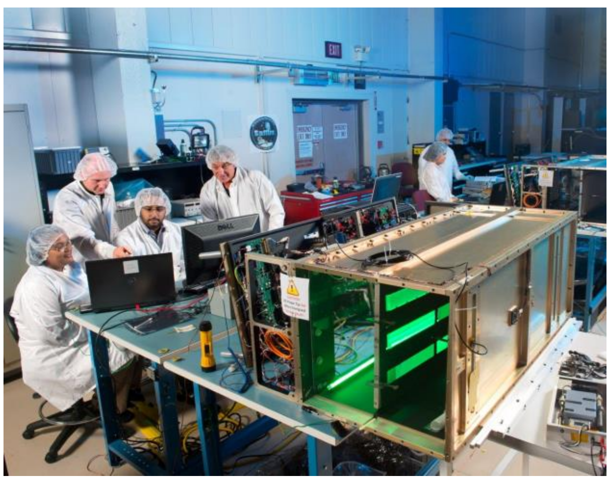
## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Total Budget | 189.2 | -- | 324.1 | 429.0 | 842.0 | 971.4 | 936.6 |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 includes a column for PBR 2017 which includes both Discretionary and the Mandatory Funding Initiative for R&D.*



**NASA technologists perform functional and sub-system power tests for Saffire-II and Saffire-III flight demonstrations in order to better understand how fire spreads and how to recover from fire events in microgravity. )**

AES develops foundational technologies and high-priority capabilities that will become the building blocks for future human space missions using an approach that combines focused, in-house activities with public-private partnerships to rapidly develop and test prototype systems. AES is pioneering ways to drive a rapid pace of progress, streamline management, foster partnerships with external organizations, and more effectively utilize the NASA workforce as we transition to enabling human space flight beyond low Earth orbit and on to other locations, including Mars.

NASA-led teams of engineers and technologists across the country are engaged in rapid development activities, demonstrating key capabilities in flight or flight-like environments, validating operational concepts, gaining valuable hands-on experience with hardware, and mastering the skills necessary for future space missions. The Agency is able to uncover potential risks of new capabilities before integration into more critical systems by performing early validation of complex systems, testing those systems in the proper environments, and flying the technology. Early risk reduction helps avoid cost growth and improve affordability of future space exploration.

AES activities focus on human space flight systems for deep space and robotic precursor missions to identify and fill in knowledge gaps related to potential destinations in advance of flight missions. Major areas of work include systems development for more reliable life support; deep space habitation technology; advanced in-space propulsion; advanced space suit sub-system technology; landing capabilities; in situ resource prospecting and processing; and overall capabilities to reduce logistics requirements to support future human spaceflight missions. Within this framework, AES is developing concepts and subsystems for an initial cislunar habitation capability, developing public-private partnerships for lunar lander and other capabilities, and creating the ability to support missions with the resources available at space mission destinations, such as processing the Martian atmosphere for the production of oxygen and the separation of water from regolith. These efforts will enable human space flight to become increasingly Earth independent and capable of expanding into the solar system. Through this pioneering work, we seek the capacity to learn, operate, and thrive safely in space for an extended, and eventually indefinite, period with a reduced supply chain from Earth.

NASA also continues to leverage and technically align HEOMD, STMD, and SMD core capabilities, technology developments, and innovative approaches. The ARM is an early mission in the proving ground of cis-lunar space, and provides an integrated capability demonstration for a number of systems, each important in their own right, to accomplish a range of objectives for longer term crew activities in deep space. For example, ARM leverages advanced SEP technologies in STMD and the private sector; advanced controls, sensors, and robotics technologies in ISRS; international docking system developments in the ISS program; and AES EVA activities. The advanced SEP system will place the spacecraft and asteroid boulder in orbit around the Moon; where the asteroid and robotic spacecraft can become an asset in the proving ground of cis-lunar space. In the mid-2020s, using the SLS and Orion vehicles, astronauts will visit the asteroid boulder and use advanced in-space EVA operations to collect asteroid samples and return to Earth. AES also works closely with SMD to develop instruments, support research and analysis, and plan and conduct robotic missions that are precursors for eventual human exploration.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

HEOMD is consolidating technology activities spread across multiple programs into AES in order to better align the Directorate's organizational and management structure. These activities are ongoing and provide cross-Directorate human mission architecture support, as well as crosscutting special initiatives, trades and studies. The transferred activities include Center of Excellence for Collaborative Innovation (CoECI) and its NASA Tournament Lab (NTL) work, which is advancing technical capabilities using open innovation methods and platforms. Additional activities include the Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) testbed on ISS, the CubeSat Launch Initiative, and the Evolvable Mars Campaign which is the agency's primary strategic planning and analysis activity for determining the mission scenarios and capabilities required for human space flight missions outward towards Mars.

AES will begin development of system concepts and integrated subsystems for a cis-lunar habitat and systems that will enable extended duration human missions in the Proving Ground of cis-lunar space in preparation for human missions into deep space. AES will continue the existing acquisition strategy for the cis-lunar habitat and systems by building upon the NextSTEP public-private partnerships that seek to leverage additional public sector investments to develop commercial habitats in low Earth orbit. Public-private partnerships encourage leveraging public investment with private investment to maximize the ability to meet NASA's requirements along with fostering the growth of commercial endeavors. In this specific case, these partnerships allow NASA to meet its cis-lunar habitat and systems requirements while encouraging and supporting the development of low Earth orbit commercial habitation and systems development.

## ACHIEVEMENTS IN FY 2015

In FY 2015, AES began a new set of activities to leverage past achievements from development work performed from FY 2012 – FY 2014. These activities included integrated life support, progress toward advanced space suit subsystem technology, autonomous systems and operations, modular power systems, radiation sensors, avionics and software, and instruments for the Mars 2020 mission. The cross-Directorate robotic mission element of the ARM completed the Agency's KDP-A and Acquisition Strategy Meeting milestones of formulation.

AES studied options to augment Orion's habitation and EVA capabilities for extended deep space missions. These efforts included a solicitation called the NextSTEP Broad Agency Announcement (NextSTEP BAA). This series of public private partnerships fund industry concept studies, limited capability development, and participation in formulation of habitation options. As part of this BAA, AES also funded studies and technology development work in life support, propulsion, and CubeSats for Orion EM-1. This BAA demonstrated a unique acquisition strategy where all the selected partners are providing up to 50 percent of the development cost.

AES completed development of three payloads to understand microgravity effects on large-scale fire propagation in space (Saffire, I, II and III). These payloads will be integrated with the Cygnus cargo transport vehicle. Large-scale fire demonstration on the Earth return segment of Cygnus flights will allow us to understand the fate of a spacecraft fire at relevant length and time scales. NASA will use the knowledge obtained from these experiments in detailed analysis and optimization for future fire protection systems.

AES continued developing secondary CubeSat payloads in 2015 to fly on SLS in 2018. Initial mission concept selections include Lunar Flashlight to look for lunar volatiles such as ice, BioSentinel to further study the effects of the deep space radiation environment, and Near Earth Asteroid Scout to visit candidate asteroids for future human exploration.

AES began to integrate advanced autonomy software, sensors, and feedback controls with advanced life support hardware to demonstrate improved overall efficiency and increased autonomy. For example, a controller was developed for the Cascade Distiller System (CDS), which performs a variety of water purification tasks. The controller executes a plan to operate the CDS hardware, monitor its performance, and take different control options if unexpected events occur. Increased autonomy and reliability are essential for missions beyond low Earth orbit in the context of both crew time and limited communications back to Earth.

AES completed the Instrument Accommodation Reviews for Mars 2020 mission payloads to demonstrate oxygen production from the atmosphere and measure surface weather conditions. AES conducted human-in-the-loop testing of a short-duration space suit for in-space cis-lunar missions, such as ARM. The testing also informs development concepts for instruments and EVA tools for demonstration on ARM to find potentially valuable asteroid resources such as metals and water. AES also began new efforts related to in-space manufacturing by printing new specialized tools with the 3D printer, which was recently delivered to the ISS.

AES conducted a field test of a Resource Prospector prototype rover and integrated a sampling and analysis payload. As part of integrated life support activity, AES accelerated work on three planned ISS flight demonstrations: high pressure/high purity oxygen generation system, cascade distillation system for wastewater processing, and miniature monitoring instrument for atmospheric contaminants.

ARM completed the Robotic Mission Concept Review in the spring of 2015 and the Acquisition Strategy Meeting in August, gaining authorization to proceed to Phase A. In addition, STMD and ISS/ISRS are leading efforts for long-lead ARM component acquisitions.

# ADVANCED EXPLORATION SYSTEMS

## WORK IN PROGRESS IN FY 2016

In FY 2016, AES will continue to advance technologies needed for beyond Earth orbit habitat components and integrated habitats. The BEAM will be launched to the ISS to demonstrate inflatable structures technology for deep space habitats. NextSTEP partners will complete four Phase 1 system concept studies for cis-lunar habitats, two integrated studies on habitation systems, the first phase of a ground-based proof of concept for a new alternative to carbon dioxide removal, in addition to assembling and testing a prototype docking hatch.

AES will also continue to develop and test the multiple subsystems required for the highly reliable life support systems needed in a cislunar habitation module. These include atmosphere recovery systems, increased water recovery, and smaller monitoring systems, to initially deploy for testing on the ISS and eventual use on Orion and cislunar habitation capabilities.

One of the key aspects of habitation is to understand and manage the risk related to fire in space. In FY 2016, AES plans to launch the first of three Saffire experiments to investigate the spread of large-scale fires in space. After the initial three tests are completed, the sequence of Saffire experiments will continue, with each test building upon data from the previous one, to investigate fire detection and post-fire clean up.

AES will maintain investments in efforts that reduce logistics requirements, including in-space manufacturing technology development and demonstration on ISS. The in-space manufacturing effort will develop and test 3D printing processes for metallic parts, laser scanners to measure the dimensions of 3D printed parts, and systems to recycle discarded plastic to produce feedstock for 3D printers.

AES will continue to support the Crew Module Systems AA-2 test by leading integration of the flight test vehicle. The AA-2 flight test in 2019 will demonstrate the ability of the launch abort system to function as the spacecraft breaks through the speed of sound while using AES developed avionics and core flight software that could serve as a contribution to future capabilities.

AES plans to conduct ground tests of advanced in-space propulsion technologies to reduce travel time to Mars, including high-power electric propulsion systems selected via the NextSTEP BAA.

The Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) instrument will complete its PDR and CDR.

The ARM element, incorporated into AES in FY 2015, will progress to KDP-B for the robotic mission, and leverage development of synergistic capabilities for ISRS, such as automated rendezvous and docking sensors, and autonomous robotic manipulators. NASA will continue planning for a mid-2020s crewed mission concept development, including potential U.S. and international partnerships.

# ADVANCED EXPLORATION SYSTEMS

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

As NASA works to extend human space exploration beyond low Earth orbit, AES will continue to develop reliable life support systems; deep space habitats; crew mobility systems; advanced in-space propulsion; advanced space suit sub-system technology; landing capabilities; in situ resource prospecting and processing; and overall capabilities to reduce logistics requirements to support future human spaceflight missions.

In FY 2017, AES will complete the Crew Module System AA-2 CDR. AES will continue to define system requirements, design concepts, and begin physical hardware prototyping for cis-lunar habitats and systems in Phase 2 of the NextSTEP partnerships, and formulate the transition efforts from capability investments to flight hardware for development and integrated prototyping by the end of 2018.

AES will develop and test highly reliable life support systems to deploy on ISS and Orion, including a brine processor, high pressure oxygen supply, and miniaturized environmental monitoring system. Additionally, AES will develop a prototype universal waste management system for flight demonstration on ISS and fully flight qualified system on Orion's first crewed mission.

The Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) partnership activity will continue to support commercial partners while they complete assembly of at least one flight-ready commercial lunar lander.

ARM will continue development of the robotic mission to confirmation, or KDP-C, and planning of a crewed mission, including determining what hardware (common sensors, docking, and EVA accommodations) will be needed for the robotic mission. STMD will continue to develop the high power, long life electric propulsion system and robotic tools for collecting the asteroid boulder. HEOMD will continue to development of the spacecraft bus and all other systems that will also be used on ARRM, as well as many other human spaceflight system and technologies necessary to create a sustainable exploration strategy.

AES, working closely with the private sector, will begin development of system concepts and integrated subsystems for a cis-lunar habitat and systems that will enable extended duration human missions in the proving ground of cis-lunar space in preparation for human missions into deep space. AES will continue the existing acquisition strategy for the cis-lunar habitat and systems by building upon the NextSTEP public-private partnerships, which seek to leverage additional public sector investments to develop commercial habitats in low Earth orbit.

# Program Elements

Six technology and strategic analysis elements, called "domains," drive the AES effort; each of which focuses on a specific capability required for future human space exploration. The AES budget request also includes the ARM element that utilizes on-going technology and system development efforts into an integrated capability mission.

# ADVANCED EXPLORATION SYSTEMS

## HABITAT SYSTEMS

The focus of the Habitat Systems domain is enabling the crew to live and work safely in deep space. Activities include the expandable habitat BEAM, NextSTEP deep space habitation development efforts, reliable life support systems, logistics reduction, and radiation measurements and protection. Experiments to improve spacecraft fire safety are also underway to better understand how fire spreads, and how to recover from fire events in microgravity. These investments will progressively move from habitation sub-systems to integrated systems and then transition to the capabilities to define, design, and develop cis-lunar habitation capabilities and systems for use in conjunction with Orion and SLS on Exploration Missions in the Proving Ground.

## CREW MOBILITY SYSTEMS

The Crew Mobility Systems domain encompasses capabilities that enable the crew to conduct “hands-on” exploration and in-space operations. EVA and space suit sub-system technology advancements will lead to next generation space suits and portable life support systems in the future that are significant advancements beyond the current capabilities used today that rely on technology developed over 30 years ago. These enhancements will give astronauts improved dexterity and mobility in space environments, higher levels of reusability in addition to mission kits, and general crew tools and mobility aids. Out year plans include developing new prototype sub-systems. The initial focus will be on infusing a modular approach to a next-generation in-space exploration suit capability to allow future upgrades for planetary surface exploration.

## VEHICLE SYSTEMS

Within the Vehicle Systems domain are efforts to develop technologies needed for advanced in-space propulsion stages and small robotic landers. Activities which will benefit future robotic and human missions by improving autonomous precision landing on planetary surfaces, as well as potential new propellants and/or propulsion systems. NASA shares these landing capabilities through public-private partnerships with industry under the Lunar CATALYST initiative. Other ongoing initiatives include work on advanced propulsion under the NextSTEP BAA awards and modular power for multiple exploration vehicles and systems such as fuel cells.

## FOUNDATIONAL SYSTEMS

The Foundational Systems domain focuses on systems to enable more efficient mission and ground operations, and those that allow for more Earth independence, including autonomous mission operations, avionics and software, in-situ resource utilization, in-space manufacturing, synthetic biology, and communications and networking technologies.

# ADVANCED EXPLORATION SYSTEMS

## ROBOTIC PRECURSOR ACTIVITIES

Robotic Precursor Activities focus on developing robotic missions and instruments to provide data and information for analyzing the feasibility of potential destinations for human missions. Current activities include RAD instrument operations on the Curiosity rover to measure the radiation environment on Mars, the internal and public-private partnership EM-1 secondary missions, and instruments planned for the Mars 2020 rover mission.

## STRATEGIC OPERATIONS, INTEGRATION, AND STUDIES

AES leads the Agency's deep-space human spaceflight architecture and strategic planning (Evolvable Mars Campaign), including mission and systems analysis and international coordination. It conducts studies and analysis to translate strategy into developmental (technology and capability) priorities and operational efficiencies.

## ASTEROID REDIRECT MISSION

The ARM element includes ARRM work through the insertion of on-going technology and system development deliverables, such as electric propulsion systems from STMD, in an integrated robotic capability demonstration. It also includes early planning for a crewed mission, as well as tools and systems to the robotic spacecraft to support the later human spaceflight mission in cis-lunar space.

There are three main segments to ARM: identify ground and space-based assets that detect and characterize potential target asteroids; redirect an asteroid to cis-lunar space via a solar-electric propulsion - based system; and explore the redirected asteroid via SLS rocket and Orion spacecraft and return samples to Earth. An early mission in the proving ground of cis-lunar space, ARM provides an integrated capability demonstration for a number of systems, each important in their own right, to accomplish a range of early step objectives for eventual longer-term crew activities in deep space.

## Program Schedule

| Date | Significant Event |
|---|---|
| Jan 2016 | Launch BEAM to ISS |
| Jan 2016 | MOXIE Preliminary Design Review |
| Mar 2016 | Saffire-I fire safety experiment launch |
| Apr 2016 | Complete lunar lander concept study with Taiwan |
| Apr 2016 | Complete BioSentinel CDR |
| Apr 2016 | Spacecraft Atmosphere Monitor System Design Review |
| May 2016 | Ascent Abort-2 Systems Requirements Review |
| Jun 2016 | Saffire-II fire safety experiment launch |
| Jun 2016 | Lunar CATALYST commercial lander CDR |
| Aug 2016 | NextSTEP electric propulsion subsystems complete for thruster testing |
| Sep 2016 | MOXIE CDR |
| Sep 2016 | Complete NextSTEP habitat system studies with commercial partners |
| Q4 2016 | Asteroid Redirect Robotic Mission (ARRM) KDP-B |
| Q1 2017 | Saffire-III fire safety experiment launch |

## Program Management & Commitments

HEOMD executes AES activities, and the Directorate's Associate Administrator has delegated management authority, responsibility, and accountability to the AES Division at NASA Headquarters. The AES Division establishes overall direction and scope, budget, and resource allocation for activities implemented by the NASA centers.

AES, STMD, and the Planetary Science Division within SMD jointly fund robotic precursor activities, developing instruments to include on NASA's science and international missions. AES coordinates with the STMD and SMD on Robotic Precursors planning and execution.

NASA Headquarters has delegated HEOMD overall management authority, responsibility, and accountability for ARM. STMD maintains responsibility for the SEP system and SMD maintains responsibility for asteroid target identification. The governance of ARRM is further defined by the Memorandum of Agreement between HEOMD and STMD.

# ADVANCED EXPLORATION SYSTEMS

| Program Element | Provider |
|---|---|
| Crew Mobility Systems | Provider: NASA Centers<br>Lead Center: Headquarters (HQ)<br>Performing Center(s): JSC and GRC<br>Cost Share Partner(s): N/A |
| Habitat Systems | Provider: NASA Centers<br>Lead Center: HQ<br>Performing Center(s): JSC, MSFC and JPL<br>Cost Share Partner(s): Bigelow Aerospace, Boeing, Lockheed Martin, Orbital ATK (NextSTEP). |
| Vehicle Systems | Provider: NASA Centers<br>Lead Center: HQ<br>Performing Center(s): GRC, JSC, MSFC, and JPL<br>Cost Share Partner(s): Ad Astra, Aerojet Rocketdyne, MSNW (NextSTEP). |
| Foundational Systems | Provider: NASA Centers<br>Lead Center: HQ<br>Performing Center(s): ARC, JSC, KSC, and MSFC<br>Cost Share Partner(s): Department of Defense |
| Robotic Precursor Activities | Provider: NASA Centers<br>Lead Center: HQ<br>Performing Center(s): ARC, JPL, MSFC, and KSC<br>Cost Share Partner(s): SMD, STMD, Morehead State University, Lockheed Martin (NextSTEP) |
| Strategic Operations, Integration, and Studies | Provider: NASA Centers<br>Lead Center: HQ<br>Performing Center(s): ARC, JPL, JSC, MSFC, and KSC<br>Cost Share Partner(s): Launch Services Program, SMD, ISS |
| Asteroid Redirect Robotic Mission | Provider: NASA Centers<br>Lead Center: JPL<br>Performing Centers: GRC, GSFC, LaRC, KSC<br>Cost Share Partners: N/A |

## Acquisition Strategy

AES selected initial activities through an internal competition in which NASA centers submitted proposals specifically to address the highest priority capabilities for human exploration beyond low Earth orbit, which are represented through the AES domains. Each year, AES evaluates how the portfolio aligns with human exploration priorities and technology gaps, and either terminates activities that do not demonstrate adequate progress or realigns them, and/or adds new activities to the portfolio as appropriate.

# ADVANCED EXPLORATION SYSTEMS

Teams are provided limited procurement funding to purchase materials, equipment, and access and coverage of NASA test facilities. AES strives to maximize specialized skills within the civil service workforce, but may also utilize a small amount of contractor effort in areas where NASA can cost effectively leverage external skills and knowledge.

AES continues to increase the use of competitively selected external awards and public-private partnerships. For example, in FY 2015 AES awarded 12 NextSTEP BAAs, allowing NASA to pursue public-private partnerships for advanced habitation and life support, high-power electric propulsion systems testing, and small satellites for launch on SLS. AES plans to continue with additional phases of the previously awarded NextSTEP BAA activities as soon as feasible and then issue a new NextSTEP BAA, open to new applicants, to involve commercial and university partners in architecture studies, in situ resource utilization technology development, lunar landing services, and instruments for precursor measurements.

In FY 2016, AES plans to release a joint BAA with the Defense Advanced Research Projects Agency (DARPA) related to the advancement of in-space manufacturing.

In FY 2015, ARM completed the ARRM Acquisition Strategy Meeting with a focus on the acquisition of the spacecraft bus leveraging commercially available spacecraft bus capabilities. JPL has released a commercial leveraged spacecraft bus study request for proposal. STMD electric propulsion development contract proposals are under evaluation.

## MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Crew Mobility Systems: Space Suit | ILC Dover | JSC |
| Habitat Systems: Life Support System Components | Hamilton Sundstrand | MSFC and JSC |
| Habitat Systems: Inflatable Module | Bigelow Aerospace | JSC |
| Habitat Systems: Passive Common Berthing Mechanism | Sierra Nevada Development Corporation | JSC |
| Vehicle Systems: Lander Capabilities | Moon Express, Astrobotic Technologies, and Masten Space Systems | MSFC, JSC, and KSC |
| NextSTEP BAA Awards | Boeing, Bigelow Aerospace, Lockheed Martin, Orbital ATK, Dynetics, Hamilton Sundstrand, Orbitec, Ad Astra, Aerojet Rocketdyne, MSNW, Morehead State University | Various industry locations |

# ADVANCED EXPLORATION SYSTEMS

## INDEPENDENT REVIEWS

AES undergoes quarterly Directorate Program Management Council reviews and periodically, representatives from the Office of Chief Engineer, the Office of Safety and Mission Assurance, and the Office of Chief Financial Officer will assess AES performance during Agency-level Baseline Performance Reviews (BPR). In addition, AES provides briefing reports to, and seeks feedback on planning and development activities from, the NASA Advisory Council Human Exploration and Operation Committee and the Technology, Innovation, and Engineering Committee. The ARRM has established a Standing Review Board for independent review and reports to the Agency level BPR.

# ASTEROID REDIRECT ROBOTIC MISSION

| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **0.0** | **--** | **66.7** | **131.0** | **355.0** | **406.0** | **202.3** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

*FY 2017 includes a column for PBR 2017 which includes both Discretionary and the Mandatory Funding Initiative for R&D.*

**ARRM Enables Crewed Mission in the Mid-2020s (Artist Rendering))**

### PROJECT PURPOSE

ARM provides an integrated capability demonstration for a number of systems, each important in their own right, to accomplish a range of objectives. An early mission in the proving ground of cis-lunar space, ARM human space flight demonstration objectives are an important early step to longer term crew activities in deep space. There are three main segments to ARM: identify ground and space-based assets which detect and characterize potential target asteroids; redirect the asteroid to cis-lunar space via a SEP-based system; and explore the redirected asteroid via SLS rocket and Orion spacecraft and return samples to Earth.

Candidate asteroids are already being identified by the Near-Earth Object Observations Program in SMD. ARRM is in the formulation phase and will provide the second ARM segment. ARRM will be the first mission to utilize an advanced high-power, high-throughput, long-life SEP system, developed by STMD, to ferry a multi-ton object through interplanetary space. The Asteroid Redirect Crewed Mission planned for the mid-2020s is in pre-formulation and enabled by the robotic mission. Key contributions of space flight technologies and operational experience needed for human missions to Mars, including: transporting multi-ton objects with advanced solar electric propulsion; integrating crewed/robotic vehicle operations in deep space staging orbits; utilizing advanced autonomous proximity operations and rendezvous in deep space and with non-cooperative objects; conducting astronaut EVAs for sample selection, handling, and containment; maintaining Earth return trajectories; and strategies for emergency returns.

# ASTEROID REDIRECT ROBOTIC MISSION

| Formulation | Development | Operations |
| --- | --- | --- |

For further programmatic information, go to:

https://www.nasa.gov/mission_pages/asteroids/initiative/index.html.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

The ARRM integrated capability demonstration mission entered Phase A of Project Formulation in March 2015. During Phase A, the team defines the technical systems and resource requirements expected for the selected mission concept. This work, along with interactions from stakeholders, helps refine a mission concept.

## PROJECT PRELIMINARY PARAMETERS

ARRM FY 2017 budget request supports continued mission formulation supporting a mid-2020s crewed mission date. NASA will continue formulation in FY 2017, leading to refinement of the launch date and other Agency commitments, including spacecraft bus development start.

## ACHIEVEMENTS IN FY 2015

ARRM concluded 18 BAA study contracts providing input into: capture system options; rendezvous and proximity operations sensors; options to adapting commercial spacecraft; and future partnerships for secondary payloads and the crewed mission. ARRM completed a robotic mission capture concept downselect decision and, in conjunction with other early critical design and acquisition meetings, received approval to enter Phase A (KDP-A). NASA approved Draft Level 1 mission requirements and formulation guidance for launch dates. The ARRM team also requested ideas through a Request for Information (RFI) to support acquisition strategy activities. The ARRM Acquisition Strategy Meeting had a focus on acquisition of the spacecraft bus leveraging commercially available spacecraft bus capabilities.

NASA continues to make the following progress on essential activities that can be utilized on ARRM: began long lead component technology procurements for SEP technology demonstration mission (STMD); developed robotic systems and controls for interaction with non-cooperative bodies (HEOMD/ISS); and matured interfaces to the crewed mission, such as EVA technology maturation (HEOMD/AES).

## WORK IN PROGRESS IN FY 2016

ARRM is conducting competitively solicited early design phase study contracts for robotic spacecraft and finalize Phase A to design this integrated capability demonstration mission. ARRM integrated requirements closure was successfully conducted in December 2015.

This FY 2017 budget request for ARRM will enable NASA to continue U.S. and international partnerships development and prepare for spacecraft bus development. Also with partners and synergistic programs, ARRM will continue long lead procurement activities related to spacecraft bus or SEP module and capture module: The STMD SEP project will continue high power, long life solar electric propulsion

# ASTEROID REDIRECT ROBOTIC MISSION

| Formulation | Development | Operations |
|---|---|---|

system technology development toward demonstration on ARRM; and will also continue to advance satellite servicing autonomy, controls, and robotic manipulators. ARRM will also benefit from SMD asteroid observations and enhancements for target identification.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

ARRM will continue competitive industry early design activities for the spacecraft bus. The capture systems and module will continue development efforts. Including defining Potential international and commercial partnerships. SMD will conduct further asteroid observations and enhancements.

## ESTIMATED PROJECT SCHEDULE

Project schedule estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation at KDP-C.

| Milestone | Formulation Authorization Document | FY 2017 PB Request |
|---|---|---|
| KDP-B | Q2, FY 2016 | Q4, FY16 |
| SDR, KDP-C | N/A | TBD |
| SDVR | N/A | TBD |
| Launch (or equivalent) | Dec 2020 | TBD |

# Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review.

# ASTEROID REDIRECT ROBOTIC MISSION

| Formulation | Development | Operations |
|---|---|---|

## Project Management & Commitments

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| STMD EP | Demonstrate a high power solar electric propulsion system, enabling a capability for future deep space human and robotic exploration, with applicability to the Nation's public and private sector space needs. | Provider: STMD<br>Lead Center: GRC<br>Performing Center(s): GRC, JPL<br>Cost Share Partner(s): | |
| SMD Target Identification | Utilize detection, tracking and characterization data of Near-Earth Asteroids, enabling continued search for candidate ARM target asteroids. | Provider: SMD<br>Lead Center: JPL<br>Performing Center(s): JPL<br>Cost Share Partner(s): N/A | |
| Capture Module | Develop asteroid boulder capture module leveraging in-space robotic servicing systems developments | Provider: GSFC<br>Lead Center: GSFC<br>Performing Center(s): GSFC, LaRC, JPL<br>Cost Share Partner(s): | |
| Launch Vehicle | TBD | Provider:<br>Lead Center:<br>Performing Center(s):<br>Cost Share Partner(s): | |

## Project Risks

Project risk(s) estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review.

## Acquisition Strategy

JPL manages the ARRM project, including acquisition of a SEP based spacecraft bus, which significantly leverages existing commercially available SEP capable spacecraft busses.

# ASTEROID REDIRECT ROBOTIC MISSION

| Formulation | Development | Operations |
|---|---|---|

## MAJOR CONTRACTS/AWARDS

A HEOMD commercial leveraged spacecraft bus study request for proposal is released. STMD EP development contract proposals are under evaluation.

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Performance | Independent Review Team, Agency Program Management Council | Mar 2015 | Mission Concept Review | Successful | N/A |
| Performance | SRB, Agency Program Management Council | Q4, FY 2016 | KDP-B (includes SRR, Mission Definition Review (MDR) | Pending | N/A |

# SPACE OPERATIONS

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Space Shuttle | 7.7 | -- | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| International Space Station | 1524.8 | -- | **1430.7** | 1554.7 | 1536.8 | 1539.3 | 1585.2 |
| Space Transportation | 2254.0 | -- | **2757.7** | 2475.0 | 2118.7 | 2144.4 | 2213.9 |
| Space and Flight Support (SFS) | 839.0 | -- | **887.4** | 883.2 | 874.1 | 856.4 | 898.6 |
| **Total Budget** | **4625.5** | **5029.2** | **5075.8** | **4912.8** | **4529.7** | **4540.1** | **4697.6** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

# SPACE OPERATIONS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Space Shuttle | 7.7 | -- | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| International Space Station | 1524.8 | -- | **1430.7** | 1554.7 | 1536.8 | 1539.3 | 1585.2 |
| Space Transportation | 2254.0 | -- | **2757.7** | 2475.0 | 2118.7 | 2144.4 | 2213.9 |
| Space and Flight Support (SFS) | 839.0 | -- | **887.4** | 883.2 | 874.1 | 856.4 | 898.6 |
| **Total Budget** | **4625.5** | **5029.2** | **5075.8** | **4912.8** | **4529.7** | **4540.1** | **4697.6** |
| Change from FY 2016 | | | **46.6** | | | | |
| Percentage change from FY 2016 | | | **0.9%** | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**NASA astronaut Kjell Lindgren captured while working outside of ISS during a spacewalk on Nov. 6, 2015. Lindgren and fellow NASA astronaut Scott Kelly restored the port truss (P6) ammonia cooling system to its original configuration and returned ammonia to the desired levels in both the prime and back-up systems.**

NASA's exploration of deep space is rooted in an operational experience base a half century long. As it prepares once again to stretch human exploration beyond low Earth orbit, the Agency is drawing from the best that five decades of human space flight has to offer.

Space Operations capabilities enable rocket propulsion testing; assure safe, reliable, and affordable access to space; and maintain secure and dependable communications with crewed and robotic missions across the solar system and beyond. Programs in the Space Operations portfolio promote full utilization of the ISS for conducting research and technology development. Activities cover all aspects of ISS operation and resupply, including on-orbit operations, crew training and transfer, and cargo replenishment.

The Commercial Crew Program (CCP) will provide reduced reliance on foreign providers for U.S. crew access to low Earth orbit and CCP's partnerships with the private sector develop commercial systems capable of carrying humans to and from the ISS, similar to the successful approach demonstrated for cargo resupply services.

The 21st Century Space Launch Complex (21CSLC) initiative will conclude at the end of fiscal year (FY) 2017. Kennedy Space Center (KSC) will complete a number of infrastructure modernization projects, including refurbishing the wharf at the Turn Basin at KSC, additional conditioning of the Launch Complex 39 (LC-39), crawlerway and roof replacement of the KSC Logistics facility. Key projects at

Wallops Flight Facility (WFF), such as Range Control Center upgrades, modernization of the Bermuda tracking facility, and performance test on Pad OA, will all be completed in FY 2016.

For further programmatic information, go to http://www.nasa.gov/directorates/heo/home/ index.html.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

Starting with the FY 2016 Appropriation, CCP has been realigned from the Exploration account to the Space Operations account within the Space Transportation Theme for increased synergy with the ISS Program. Previously within the ISS Program, ISS Crew and Cargo Transportation has also moved to the Space Transportation Theme.

NASA transferred In-Space Robotic Servicing (ISRS) from ISS Research to Space Technology Mission Directorate (STMD).

## ACHIEVEMENTS IN FY 2015

Commercial providers successfully launched two cargo resupply missions to the ISS in FY 2015, carrying critical investigations, experiments, and supplies.

NASA's industry partners successfully worked throughout the year to complete their contracted milestones, leading to production of a viable crewed space transportation system that will reduce our reliance on foreign providers. For example, under the Commercial Crew transportation Capabilities (CCtCap) contracts Boeing has completed six of 23 development milestones, including a key Delta I – Critical Design Review (CDR) milestone and SpaceX has completed two of 18 development milestones, including an Avionics Test Bed milestone.

Future long-duration human spaceflight and exploration activities require research that can only be accomplished on the ISS. These activities are integral to understanding and mitigating the impacts of long-duration space flight on human health. ISS hosted 416 experiments in a wide range of various scientific and technology areas, including experiments with a 3D printer, which will enable the crew to manufacture specialized tools and parts on demand. This research supports future long-duration human spaceflight. Some examples of research include the Vegetable Production System (Veggie), verifying microgravity-grown plants do not harbor potentially harmful microorganisms, and Fruit-Fly Lab 1 designed for further research into human genetic responses to long-duration stays in space.

American Astronaut Scott Kelly and Russian Cosmonaut Mikhail Kornienko began a one-year ISS expedition in March 2015, to better understand the impacts of long-duration space flight on the human body and aid in the development of effective countermeasures.

Launch Services Program (LSP) supported the launch of the Soil Moisture Active Passive (SMAP) and the Magnetospheric Multiscale (MMS) missions. LSP ensures these missions reach space by acquiring commercially available launch services and working with customers and providers, from pre-mission planning through post-launch.

Space Communications and Navigation (SCaN) supported over 30 missions, with over 178,000 hours of tracking and more than 160,000 passes. During the fiscal year, SCaN successfully supported downloading scientific data from the New Horizons spacecraft in July 2015 as it passed Pluto and its moon Charon.

NASA continues to replenish SCaN's networks to resolve ongoing equipment obsolescence ensuring that future deep space missions have the communication capabilities needed to be successful. The Space Network Ground Segment Sustainment (SGSS) project completed integrated software and system development activities furthering ground system performance, capability, and robustness.

Rocket Propulsion Testing (RPT) performed the first RS-25 engine test on Stennis Space Center (SSC) A-1 test stand. This successful 300-second test began a multi-year effort necessary to use the engine on SLS Core Booster Stage, which is required to support Exploration Mission (EM)-1 and other exploration goals. Testing the propulsion systems that will transport astronauts to cis-lunar space and beyond is critical to future mission success, and RPT provides that support.

## WORK IN PROGRESS IN FY 2016

Commercial Crew industry teams will complete remaining Commercial Crew Integrated Capability (CCiCap) milestones and achieve significant milestones as part of their CCtCap contract(s). These milestones will demonstrate that commercial providers are continuing to mature their capabilities towards NASA's goal of launching astronauts once again to ISS from U.S. soil.

To ensure visiting vehicle traffic flexibility and port redundancy, ISS will be moving several pressurized modules. A commercial provider will launch a commercial inflatable structure (known as BEAM) to ISS to investigate habitat technology, a critical requirement for future exploration missions.

Human Exploration and Operations Mission Directorate (HEOMD) and its international partners continue to maintain and operate ISS as a platform for research and to expand the commercial utilization of low Earth orbit. NASA's new "open science" approach will greatly expand availability of data to a larger research community, maximizing return on investment, and opening up new findings in research and technology development.

The yearlong U.S. and Russian crew expedition concludes in spring 2016. Health monitoring, clinical services and rehabilitation to the returning astronaut, and analysis of mission data will continue through the end of 2016. Furthermore, NASA will continue taking advantage of the rare opportunity to study identical twins Mark and Scott Kelly in real time on the genetic level. Studying the effects of space travel on identical twins will help researchers further the fieldwork of psychology, physiology, microbiology, and immunology.

SCaN's Deep Space Network (DSN) Aperture Enhancement Project (DAEP) work planned at Madrid Deep Space Communication Complex (MDSCC) includes construction of two new 34-meter antennas, Deep Space Station (DSS) 56 and 53. SCaN is also continuing research into Disruption Tolerant Network techniques, allowing science data to be downlinked to many space and ground assets and re-assembled safely and securely at a final destination. SCaN represented NASA with the State Department and other Federal Agencies at the International Telecommunication Union's World Radio communication Conference in November 2015 in national and international negotiations on key items related to NASA's spectrum requirements.

Space Flight Support programs are providing the capabilities needed for NASA's missions and goals: affordable launch services, propulsion testing facilities, and reliable space communications. Beginning in FY 2016, Space Flight Crew Operations will begin training astronauts in support of the first human commercial space vehicle to ISS. The new astronaut class selection process focuses on the skills critical for missions beyond low Earth orbit. Assessments will include training in smaller vehicles without the benefit of real-time communication with the ground, further enabling less reliance on Earth based capabilities.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA expects Commercial crew industry CCtCap teams will accomplish significant milestones under their contracts, including the Boeing Crewed Flight Test Readiness Review and the SpaceX Flight to ISS with Crew milestone.

NASA and international partners will manage resources, logistics, systems, and operational procedures required to maintain a continuous six-crew member capability on ISS. The ISS team will complete a second international docking adapter, to support a second docking port for commercial crew vehicles, supporting increased on-board research activity. ISS will also host a number of important Earth climate-focused research projects and the robust Center for the Advancement of Science in Space (CASIS) pipeline of projects.

Space Flight Support programs are providing the capabilities needed for NASA’s missions and goals: affordable launch services, propulsion testing facilities, and reliable space communications. In addition, LSP will support six civil sector missions for launch in FY 2017, Cyclone Global Navigation Satellite System (CYGNSS), Geostationary Operational Environmental Satellite-R (GOES-R), Joint Polar Satellite System 1 (JPSS-1), Ionospheric Connection Explorer (ICON), and Transiting Exoplanet Survey Satellite (TESS).

The Tracking and Data Relay Satellite (TDRS)-M spacecraft will be removed from storage and delivered to a launch service provider at KSC in preparation for launch in 2017.

# Themes

## INTERNATIONAL SPACE STATION

November 2015 marked the 15th anniversary of continuous human presence aboard the space station. ISS has hosted more than 200 people from 17 countries, and is the culmination of one of the largest and most complicated international engineering efforts ever attempted. It is a key step in the human endeavor to explore and live in space, providing a laboratory and crew in orbit to conduct research to advance biology and biotechnology, materials and physical science, and the effects of long-duration space flight on the human body. The ISS enables researchers to identify risks to crew, and then develop and test countermeasures to reduce those risks. NASA scientists have identified 30 health risks in human exploration of Mars, and the ISS is required to resolve at least 24 of them. In addition, the results of the research completed on ISS advance many areas of science, enabling benefits such as next-generation technologies in health and medicine, robotics, manufacturing, and propulsion.

The ISS program also includes on-orbit vehicle operations. These operations and crew and cargo transportation supplied by the Crew and Cargo Program are key to deliver the research needed to enable future long-duration human missions in deep space.

# SPACE OPERATIONS

## SPACE AND FLIGHT SUPPORT

Space and Flight Support (SFS) consists of multiple programs, providing Agency-level capabilities critical to the success of NASA missions and goals. The Human Space Flight Operations program ensures that NASA astronauts are fully prepared to carry out current and future missions safely. The LSP assures reliable access to space by providing leadership, expertise, and cost-effective expendable launch vehicle services for NASA missions. The 21CSLC Program ensures NASA's launch facilities are ready to support future commercial, as well as NASA, missions. The SCaN program downloads the science data payoff from NASA's robotic spacecraft and human missions through an extensive network of ground-based and orbiting communications nodes and associated hardware and software. The RPT program maintains a wide variety of test facilities that enable NASA, other agencies, and commercial partners to advance their rocket development efforts in a cost-effective manner.

## SPACE TRANSPORTATION

The Space Transportation theme's objective is to transport U.S. astronauts and cargo safely to and from low Earth orbit, including ISS, and partner with the U.S. private sector in developing and operating safe, reliable, and affordable transportation options. This newly created theme combines CCP and ISS Crew and Cargo Transportation. While this is a new theme in 2017, the projects under this theme existed in the FY 2016 budget structure within HEOMD. CCP was previously in the Exploration account under the Commercial Spaceflight Theme. ISS Crew and Cargo Transportation was in the Space Operations account within the ISS program.

# INTERNATIONAL SPACE STATION PROGRAM

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| ISS Systems Operations and Maintenance | 1113.0 | -- | **1108.9** | 1245.6 | 1196.3 | 1192.6 | 1232.5 |
| ISS Research | 411.8 | -- | **321.9** | 309.1 | 340.5 | 346.7 | 352.6 |
| **Total Budget** | **1524.8** | -- | **1430.7** | **1554.7** | **1536.8** | **1539.3** | **1585.2** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**Hurricane Jimena was a category 3 storm and was about 1,000 miles east of Hawaii, traveling at a rate of 10 mph in a west-northwest direction. The ISS captured this image on August 30, 2015. The ISS contributes to humanity by collecting data on the global climate, environmental change and natural hazards using its unique complement of crew-operated and automated Earth-observation payloads.**

The International Space Station (ISS) is a highly complex facility that provides an unparalleled capability for human, space-based research. A crew of six aboard the ISS—three on the US operating segment and three on the Russian segment—orbits the Earth about every 90 minutes. The U.S. operating segment is the portion of ISS operated by the United States and its Canadian, European, and Japanese partners. Russia exclusively operates the Russian segment.

Including its solar arrays, the ISS spans the area of a U.S. football field (with end zones) and weighs over 860,000 pounds, excluding visiting vehicles. Orbiting Earth 16 times per day at a speed of 17,500 miles per hour, the ISS maintains an altitude that ranges from 230 to 286 miles. The complex has more livable room than a conventional five-bedroom house, with two bathrooms, a fitness center, a 360-degree bay window, and state of the art scientific research facilities. In addition to external test beds, the U.S. operating segment of the ISS houses three major science laboratories (U.S. Destiny, European Columbus, and Japanese Kibo).

In January 2014, the Administration announced the United States' intention to extend the ISS operations and utilization to at least 2024. This extension provides nearly another decade of opportunity in which to accomplish three major objectives on the ISS: conduct research and technology development required to enable human exploration in deep space and eventually Mars; facilitate maturation of a commercial market for space-based research and activity in low Earth orbit; and conduct research in Earth, space, and fundamental biological and physical sciences.

The ISS is essential to move human exploration of space from an Earth-reliant to an Earth-independent capability. The ISS is the only microgravity platform for the long-term testing of new life support and crew health systems, advanced habitat modules, and other technologies needed to decrease reliance on Earth. Over the next decade, we will validate many of the capabilities needed to maintain a healthy and productive crew in deep space. Currently manifested or planned experiments and demonstrations include improved long-duration life support for Mars missions, advanced fire safety equipment, next-generation spacesuit technologies, high-data-rate communications, techniques to reduce logistics, large deployable solar arrays, in-space additive manufacturing, advanced exercise and medical equipment, radiation monitoring and shielding, human-robotic operations, and autonomous crew operations. The facility enables scientists to identify and quantify risks to human health and performance, and to develop and test countermeasures and technologies to protect astronauts during extended human space exploration.

The ISS program aims to provide direct research benefits to the public through its operations, research, and technology development activities. As a National Laboratory, the ISS enables partners in government, academia, and industry to utilize its unique environment and advanced facilities to perform investigations. Observing from and experimenting aboard the ISS provides the chance to learn about Earth, life, and the solar system from a very different frame of reference. NASA and its partners also use this unique reference point to advance science, technology, engineering, and mathematics efforts to inspire youth to pursue those fields. The results of the research completed on the ISS can be applied to many areas of science, improving life on this planet, and furthering the experience and increased understanding necessary to journey to other worlds.

For additional information on the ISS program, go to https://www.nasa.gov/mission_pages/station/main/index.html.

For specific information on the many experiments conducted on ISS, go to https://www.nasa.gov/mission_pages/station/research/experiments_category.html.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

NASA transferred ISRS from ISS Research to STMD. ISS Crew and Cargo Transportation has been transferred to a new theme within Space Operations, Space Transportation.

# ISS SYSTEMS OPERATIONS AND MAINTENANCE

| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **1113.0** | **--** | **1108.9** | **1245.6** | **1196.3** | **1192.6** | **1232.5** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**ISS uses the Water Recovery System to reclaim waste water from astronauts and the environment and turn it into potable water. NASA astronaut, Scott Kelly tweeted out this image of coffee from a drink bag made with this reclaimed water saying: "Recycle Good to the last drop! Making pee potable and turning it into coffee on @space station. #NoPlaceLikeHome."**

ISS is a complex research facility and human outpost in low Earth orbit, developed in a collaborative, multinational effort to advance exploration of the solar system, enable unique scientific research, and promote commerce in space.

Many things taken for granted on Earth are not available in space. Safely operating the ISS in the severe conditions of space and ensuring crew always have a sufficient supply of food, water, and oxygen requires precise planning and logistics. Much like a house, the ISS needs routine maintenance and is subject to unexpected mechanical failures. However, the systems on the ISS are significantly more complicated than systems in an average home. Resolving problems can be challenging and often require the crew to make repairs in space with support from ground teams on Earth. Astronauts on the ISS cannot go to the local hardware store to buy materials, so support teams on Earth monitor and painstakingly plan for replacement parts and consumables, such as filters, to make sure they are available when needed.

The coordination and support necessary for the ISS crew to live and work comfortably in space requires intensive Earth-based mission operations. Ground teams continually monitor ISS performance, provide necessary vehicle commands, and communicate with the crew. Even before the astronauts leave Earth, the Systems Operations and Maintenance project provides the crew training to prepare them for their stay aboard the ISS.

The ISS program considers all aspects of the mission when developing operations plans to meet program objectives. These include scheduling crew activities, choreographing the docking and undocking of visiting crew and supply ships, evaluating consumables supply, and managing stowage issues. The Systems Operations and Maintenance project ensures that the ISS is operational and available to perform its research mission at all times.

# ISS SYSTEMS OPERATIONS AND MAINTENANCE

| Formulation | Development | Operations |
|---|---|---|

Because the ISS is an international partnership, these program decisions are not made in isolation; they require collaboration with multiple countries to ensure all technical, schedule, and resources supply considerations are taken into account. The experience NASA is gaining through integration with its ISS partners is helping the Agency to better prepare for future partnerships in human space exploration.

A critical component of the Systems Operations and Maintenance project is immediate, emergency services and analyses conducted by mission control teams on Earth, known as vehicle and program anomaly resolution. Engineers and operators diagnose system failures and develop solutions, while program specialists respond to changing program needs and priorities through replanning efforts.

This year presented one of the ISS program's toughest logistical challenges. Over the course of eight months, three cargo resupply vehicles were lost in launch mishaps: Orbital ATK's Orb-3 failed immediately after launch on October 28, 2014; Russia's Progress 59P was lost just before reaching orbit on April 28, 2015; and SpaceX (SpX)-7 was lost a few minutes into flight on June 28, 2015. The ISS program was well positioned to mitigate adverse impacts. For example, consumables remain in good shape. Stockpiled research waiting to be executed is now underway with plenty of utilization time. However, key replacement ISS parts were lost in the mishaps, and combined with the low or zero inventory on Earth, presented an added challenge to the program. Two examples are the multi-filtration beds for the water processing assembly and the fluids control pump assembly for the urine processing assembly. ISS was able to procure and manifest those items on the H-II Transfer Vehicle (HTV)-5 mission. These examples are tangible evidence of the excellent forward planning by the ISS program. After losing three cargo resupply flights in about eight months, ISS was still able to support six crew members and continue a research utilization program.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None

## ACHIEVEMENTS IN FY 2015

Throughout the year, NASA ground teams continued to monitor overall vehicle health and oversee general maintenance and performance of all ISS vehicle systems, including environmental control and life support, electrical power, propulsion, thermal control; and guidance, navigation and control. During the past year, NASA detected an increase in the Total Organic Carbon (TOC) present in the onboard drinking water supply. New multifiltration beds were needed to process the excess TOC, and although the beds were lost on Orb-3 and SpX-7, the ground teams were able to modify water processing procedures on ISS to bring TOC within acceptable levels while minimizing the amount of water wasted during the processing cycle. Additionally, the team was able to manufacture, qualify, and launch new beds between SpX-7 and the HTV-5 launch, which allowed full reintegration of the water processing system and TOC levels within flight rules.

Successful operation and maintenance leads to an environment conducive to research. The ISS was host to 416 experiments. These included 118 experiments in biology and biotechnology, 66 in Earth and space science, 22 in educational activities, 84 in human research, 40 in physical science, and 86 in technology.

# ISS SYSTEMS OPERATIONS AND MAINTENANCE

| Formulation | Development | Operations |
|---|---|---|

## WORK IN PROGRESS IN FY 2016

The ISS Systems Operations and Maintenance project continues to maintain resources on orbit and on the ground to operate and utilize the ISS. NASA expects continued success in providing all necessary resources, including power, data, crew time, logistics, and accommodations, to support research while operating safely with a crew of six astronauts. NASA is planning four crew rotation and ten cargo resupply missions in FY 2016, including both international partner and U.S. commercial cargo flights.

NASA ground teams continue to monitor overall vehicle health and oversee general maintenance and performance of all ISS vehicle systems, including command and data handling, communication and tracking, crew health care, environmental control and life support, electrical power, extravehicular activities (EVAs), extravehicular robotics, flight crew equipment, propulsion, structures and mechanisms, thermal control, and guidance, navigation, and control.

The team plans to support one Russian EVA and five U.S. EVAs in FY 2016. Many of the U.S. EVAs will support continued major reconfiguration onboard ISS which began in FY 2015. NASA is continuing modifications to docking ports that will allow the ISS to accommodate two visiting vehicle-docking ports and two visiting vehicle-berthing ports, enabling traffic flexibility and port redundancy for U.S. operating segment crew and cargo vehicle missions.

While the one-year crew expedition for one Russian cosmonaut and one NASA astronaut concludes in spring 2016, data analysis will continue through the end of the year. This expedition will help scientists better understand the impacts of long-duration spaceflight on the human body, and aid in the development of effective countermeasures.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA plans to work with international partners to maintain a continuous six ISS crew member capability by coordinating and managing resources, logistics, systems, and operational procedures. The operations and maintenance project will continue to manage resource requirements and changes, including vehicle traffic, cargo logistics, stowage, and crew time. In addition to providing anomaly resolution and failure investigation as needed, they plan and provide real-time support for activities, such as EVA and visiting vehicles.

# ISS SYSTEMS OPERATIONS AND MAINTENANCE

| Formulation | Development | Operations |
|---|---|---|

## Project Schedule

The table below provides a schedule for potential EVAs. However, the ISS conducts near-term, real-time assessments of EVA demands along with other program objectives, to efficiently plan all required ISS activities. NASA remains postured to conduct EVAs on short notice in response to specific contingency scenarios. In addition, the ISS program balances routine maintenance EVAs against the overall astronaut availability to maintain focus on utilization and research.

| Date | Significant Event |
|---|---|
| Oct 2015 | U.S. EVA |
| Nov 2015 | U.S. EVA |
| Dec 2015 | U.S. EVA |
| Jan 2016 | U.S. EVA |
| Feb 2016 | Russian EVA |
| May 2016 | U.S. EVA; one contingency U.S. EVA |
| Oct 2016 | Two U.S. EVAs; Four contingency U.S. EVAs |
| Oct 2017 | U.S. EVA |

## Project Management & Commitments

While NASA maintains the integrator role for the entire ISS, each partner has primary authority for managing and operating the hardware and elements they provide. Within NASA, Johnson Space Center (JSC) in Houston, Texas leads project management of ISS Systems Operations and Maintenance.

## Acquisition Strategy

NASA extended the current Boeing vehicle sustaining engineering contract on a sole source basis to The Boeing Company through September 30, 2020. Requirements of this contract include sustaining engineering of U.S. on-orbit segment hardware and software, technical integration across all of the ISS segments, end-to-end subsystem management for the majority of ISS subsystems and specialty engineering disciplines, and U.S. on-orbit segment and integrated system certification of flight readiness.

# ISS Systems Operations and Maintenance

| Formulation | Development | Operations |
|---|---|---|

## Major Contracts/Awards

| Element | Vendor | Location (of work performance) |
|---|---|---|
| U.S. on-orbit segment Sustaining Engineering Contract | The Boeing Company | JSC |

## Independent Reviews

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Other | NASA Advisory Council | Dec 2015 | Provides independent guidance for the NASA Administrator | No formal recommendations or findings | 2016 |
| Other | NASA Aerospace Safety Advisory Panel | Dec 2015 | Provides independent assessments of safety to the NASA Administrator | No formal recommendations or findings | Feb 2016 |

# ISS RESEARCH

| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **411.8** | **--** | **321.9** | **309.1** | **340.5** | **346.7** | **352.6** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**NASA astronaut Kjell Lindgren loads a deployer device filled with 16 CubeSats into a small airlock in the Japanese Kibo Module on the ISS. Among the 16 satellites are 14 Dove satellites from Planet Labs that will be used for Earth observation, one for testing space based radios and another that will be used to track ships on the open ocean.**

The ISS is an orbiting platform that provides an unparalleled capability for space-based research and a unique venue for developing technologies for future human space exploration. As a research and development facility, the ISS enables scientific investigation of physical, chemical, and biological processes in an environment very different from Earth. A range of science laboratories, external testbeds, and observatory sites are available aboard the ISS, allowing astronauts to conduct a wide variety of experiments in low Earth orbit The ISS supports research across a diverse array of disciplines, including physics, Earth science, space science, biology and biotechnology, human physiology, chemistry, and materials science. In addition, ISS is a platform for educational activities that enable the public to engage in the national and global endeavor of human spaceflight, and inspire students to excel in science, technology, engineering, and mathematics academic disciplines.

As the name implies, the ISS is not strictly a NASA endeavor, but a collaborative venture with our international partners, including the Canadian, European, Japanese, and Russian space agencies. Although each partner has distinct national goals for ISS research, all participating agencies share a unified goal to extend the resulting knowledge for future exploration and to benefit humanity. Within NASA, mission directorates prioritize their research investments based on studies from the National Academies, such as the Decadal Survey on Biological and Physical Sciences in Space.

The ISS Research project funds fundamental and applied research in biological and physical sciences to enable future human exploration and add to our existing body of knowledge. Also funded is multi-user systems support (MUSS) capability, which provides strategic, tactical, and operational support to all NASA sponsored and non-NASA sponsored payloads (including those of the five international partners), as well as operation of on-orbit research facilities. Research-enabling activities are included as support to CASIS, a non-profit organization that manages the ISS National Laboratory.

# ISS RESEARCH

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Research and development (R&D) conducted aboard the ISS holds the promise of next-generation technologies in health and medicine; robotics, manufacturing, and propulsion; and development of applications that will benefit life on Earth. As NASA's only long-duration flight testbed, the ISS is critical to developing plans to extend human space exploration beyond low Earth orbit. Aboard the ISS, researchers study the effects of long-duration exposure to the space environment on the crew, devising and testing countermeasures to offset health risks. Additionally, researchers evaluate extended performance of equipment critical to long-duration flight by testing the hardware's ability to survive in the space environment, determining life-limiting issues and repair capabilities, and evaluating upgrades to improve performance. NASA has deployed the Disruption Tolerant Network for Space Operations on the ISS which is a step toward building a reliable Interplanetary Internet. The demonstration establishes a long-term communications test bed on the ISS capable of improving electronic communications by storing data when a connection is interrupted and forwarding to its destination using relay stations.

As of the conclusion of Expedition 44 in September 2015, more than 2,000 investigators from 83 countries around the world have performed over 1,900 research investigations utilizing the ISS and over 1,200 R&D results have been published in scientific journals and magazines (Note: these are early estimates with final numbers expected to be published in early 2016).

## EXPLANATION OF MAJOR CHANGES IN FY 2017

NASA transferred ISRS from ISS Research to STMD.

## ACHIEVEMENTS IN FY 2015

Scientific accomplishments on the ISS continue to increase, as does the quantity of data returned from automated research instruments, and astronaut crew time dedicated to research. During FY 2015, the ISS hosted 416 experiments, including an estimated 118 in biology and biotechnology, 66 in Earth and space science, 22 in educational activities, 84 in human research, 40 in physical science, and 86 in technology.

Although ISS crew visits are currently limited to six months, a U.S. astronaut and a Russian cosmonaut arrived in spring of 2015 to remain aboard for a full year of research. The 12-month study includes investigating the effects of long-term stays in space on bone density, muscle mass, strength, vision, and human physiology. While critical for future exploration missions, this and other investigations will have important applications on Earth. As a growing senior population faces a myriad of age-related health concerns, NASA's research advances knowledge of bone and muscle health, immunology, and innovative diagnostic systems, and holds promise for medical treatments on Earth.

During FY 2015, the ISS program initiated an effort to Revolutionize the ISS for Science and Exploration (RISE). This effort is reworking processes the ISS program uses for performing research on the ISS. Overall, the RISE effort will minimize the work required for a research project to fly to the ISS, so objectives are accomplished as quickly as possible.

NASA Biological and Physical Sciences (BPS) developed two new initiatives, the Physical Sciences Informatics (PSI) database and GeneLab, to allow for increased opportunities in BPS research. The PSI contains data from physical sciences experiments previously performed on the ISS, which will now create

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|---|---|---|

new open science opportunities in that field. The GeneLab Phase 1.0 database went live in April 2015, and is creating a central hub for NASA's biological open science initiative. Astronauts performed three biological open science spaceflight experiments this past year and soon NASA will release the data to the public. NASA is preparing to release the first NASA Research Announcement (NRA) for GeneLab data research in FY 2016, and released the first NRA for PSI earlier this year.

NASA completed and launched Veggie, the largest plant growth system to date for use in space. This facility is key to both studying how plants grow in space as well as determining whether humans can successfully grow food in microgravity during long-duration missions. Astronauts grew and ate lettuce to supplement their diet. The Veggie "Pick and Eat" activity was streamed live on NASA TV and was picked up by many news organizations.

NASA BPS completed Capillary Flow Experiment (CFE)-2 research on a liquid's ability to spread across a surface, and its impact over large length scales in strange container shapes in microgravity. Studying this process will help design better systems to process liquids aboard spacecraft (i.e., liquid fuel tanks, thermals fluids, and water processing for life support).

NASA completed the first phase of a new fruit fly lab (Fruit-Fly Lab 1) in 2015, enabling the study of micro- and fractional-gravity effects on animals. At first glance, fruit flies do not seem to be a good analog for humans, but on the molecular level, we share many of the same basic genes and signal transactions. Current insect research on Earth is opening new avenues for prevention and therapy to treat infections, cancer, and inflammatory disease. This new fruit fly lab will enable research into human genetic responses to long-duration stays in space.

NASA installed the externally mounted Cloud-Aerosol Transport System (CATS) on the Japanese Aerospace Exploration Agency (JAXA) External Facility. CATS uses a light detection and ranging (LIDAR) remote sensing instrument to measure atmospheric clouds and aerosols such as pollution, dust, and smoke to determine their impact to the Earth's climate. Observations of the Earth's changing atmosphere enable researchers to understand formative and ongoing processes, and, ultimately, model and predict future climate changes. The ISS orbit is particularly suited to measurements of this kind because of the geographic areas it passes over, and because it permits study of day-to-night changes, which other Earth science satellites cannot offer due to their orbits. This payload served as a pathfinder for quick turn-around, low cost science payloads and identified many areas for improvement in ISS processes that the RISE effort is addressing.

SpX-6 delivered the second rodent investigation in April 2015. A commercial company, Novartis, sponsored this musculoskeletal research. The rodent research habitats provide critical life sciences research capabilities and study physiological changes in space. Rodent research is particularly valuable because many aspects of rodent anatomy, physiology, and genetics are similar to those of humans. By studying rodents on the ISS, researchers can observe space flight-induced changes to tissues and cells, muscles and bones, cardiovascular and reproductive systems, and even behavior. This research better defines health risks and the countermeasures needed as humans expand their exploration of space and provides a platform for research into new drugs and causes of disease for application here on Earth.

Reusing hardware originally built to test parts of NASA's Quick Scatterometer (QuikScat) satellite, NASA launched the RapidScat instrument to the ISS in September to measure ocean surface wind speed

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| --- | --- | --- |

and direction. As an autonomous, externally mounted payload, this instrument is being used for near real time weather forecasts, including hurricane and cyclone monitoring, and understanding of how ocean-atmosphere interactions influence Earth's climate.

In FY 2015, CASIS engaged numerous nontraditional users and continued to enable a new era for space investigations capable of improving life on Earth. CASIS delivered 41 flight projects, led by prominent commercial companies and top academic research institutions, several in coordination with other government agency support. CASIS issued two requests for information and three research solicitations, as well as continued to build momentum in the private sector. Through such solicitations, in combination with targeted outreach activities, CASIS expects to further expand the more than 60 campaign-related projects currently in the ISS National Lab R&D portfolio.

CASIS awarded projects to improve satellite technology and biomedical knowledge on Earth through spaceflight R&D. In total, CASIS awarded 39 research and technology projects that span a wide diversity of disciplines and applications, building a pipeline of future commercial payloads in nontraditional sectors, from not only Fortune 500 companies Eli Lilly, Merck, and Milliken but also innovative startups reached through continuing partnerships with accelerators and business plan competitions. Ten awards supporting science, technology, engineering, and mathematics (STEM) education projects complement these R&D payloads.

CASIS also implemented a new research procurement strategy, termed "Sponsored Programs" or solicitations for ISS research financially supported by a sponsor organization focused on solving a specific terrestrial problem. Sponsored programs generate external funding from other outlets and leverage CASIS's ability to apportion ISS National Lab flight opportunities as an essential conduit to research and innovation. Two sponsored programs in FY 2015 included partnerships with Boeing and the Massachusetts Life Science Center, respectively. The variety of applications from these programs continues to increase, including advanced diagnostics, nanotechnologies, new biomaterials, and pandemic disease relief solutions.

NanoRacks had 49 CubeSats delivered to the ISS and 44 CubeSats were deployed successfully. There were also 34 internal payloads delivered to the ISS. The first commercially-funded external platform, the NanoRacks External Platform, was launched on HTV5. In addition, they demonstrated the first successful plant growth inside of a NanoLab, an experiment designed by students at Lakewood High School, Colorado, and delivered what is believed to be the first-ever CubeSat developed by a primary school, STMSat-1, from St. Thomas More Cathedral, Arlington, Virginia.

This year, the ISS also hosted a number of technology demonstration payloads, including a 3D printer, the Synchronized Position, Hold, Engage, Reorient, Experimental Satellites – Halo (SPHERES-Halo) and SPHERES Slosh investigations. 3D printing in zero gravity is the first step in demonstrating a machine shop, capable of creating new components in space—a critical enabling element of future exploration class missions for which resupply is difficult and costly. The SPHERES-Halo investigation studies the possibility of launching several separate components and then attaching them once they are in space. The investigation upgrades the fleet of SPHERES to enable each SPHERE to communicate with six external objects at the same time, testing new control and remote assembly methods. The SPHERES-Slosh investigation examines the way liquids move inside containers in a microgravity environment. This

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investigation will improve our understanding of how propellants within rockets behave to increase the safety and efficiency of future vehicle designs.

ISRS focused on maturing technologies and mission concepts for the Restore-L satellite servicing mission in low Earth orbit, and the Asteroid Redirect Mission (ARM). NASA completed Restore-L feasibility studies with three industry spacecraft vendors and Pre-Acquisition Strategy Meeting. Leveraging the high degree of synergy between ISRS and ARM, NASA continued technical risk reduction for ARM including rendezvous and proximity operations (RPO), high-speed avionics, and dexterous robotics. ISRS also accomplished the Robotic Refueling Mission (RRM)-2 coolant replenishment technology experiments on ISS.

For a more comprehensive list of research achievements on the ISS, go to http://www.nasa.gov/mission_pages/station/research/index.html.

## WORK IN PROGRESS IN FY 2016

Begun last year, NASA is continuing the Twins Study during Scott Kelly's yearlong stay. Identical twins like Scott Kelly and Mark Kelly are genetically almost the same, so studying them provides scientists a unique opportunity to examine how environment, diet, and other outside factors affect human health and performance. One astronaut remains in space for a year while his twin stays on Earth allowing researchers to study the effects of space travel, including genetics, psychology, physiology, microbiology, and immunology.

The GeneLab Open Science Initiative will move from phase one into phase two during FY 2016. This will involve releasing a new data system that allows researchers to search data from various data centers around the world including other government bioinformatics systems supported by the National Institutes of Health and Department of Energy.

The Packed Bed Reactor Experiment (PBRE) will launch in 2016. This investigation will focus on the role and effects of gravity on gas-liquid flow through porous media. These are critical components often found in life support systems, thermal control devices, fuel cells, and biological and chemical reactors and results of these experiments will influence future environmental control systems design.

Technology development and demonstration on the ISS is critical to exploration beyond low Earth orbit. NASA plans to launch Bigelow Expandable Activity Module (BEAM), which will demonstrate inflatable habitat technology for future human space flight and exploration activities.

Additional space exploration advancements include the Zero Boil-Off Tank (ZBOT) fluids investigation. Currently scheduled for launch in the summer of 2016, ZBOT will provide updated computer models for potential application to cryogen tank designs that could reduce propellant launch mass, and improve existing models for developing cryogen storage systems.

The Advanced Colloids Experiment-Temperature control-1 (ACE-T-1) research focuses on tiny suspended particles that have been designed to form organized structures within a liquid. The microgravity environment provides researchers insight into the fundamental physics of micro particle self-assembly and the kinds of colloidal structures that are possible to fabricate.

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The Stratospheric Aerosol and Gas Experiment (SAGE) Earth observation facility, planned for a FY 2016 launch aboard SpaceX, will record changes to the Earth's ozone layer, such as fluctuations in concentrations of greenhouse gases and thinning of the ozone layer. Scientists do not yet understand how these changes affect climate, and accurate long-term measurements such as those provided by SAGE are crucial for understanding the processes that impact climate change.

The Space Test Program Houston-5 Lightning Imaging System (STP H-5 LIS) will collect real-time lightning data, and enhance regional and global weather, climate, and chemistry studies of Earth. Current lightning data collection misses up to 30 percent of lightning activity in the northern hemisphere, which is critically needed for the National Climate Assessment. The LIS will also allow critical daytime lightning data collection to improve understanding of mechanisms contributing to ground strikes and associated electromagnetic phenomena.

The spacecraft fire experiment, Saffire, will continue in FY 2016 and FY 2017. Saffire is an international collaborative project to perform fire safety experiments on three consecutive Orbital ATK Cygnus resupply vehicle flights after they leave the ISS, and before reentry into Earth's atmosphere. The self-contained payload will test flammability of various materials in low-gravity environments to better understand the risk of fire in spacecraft. Investigating these smaller fires will further understanding of larger fires that cannot be studied in an inhabited vehicle.

The Burning and Suppression of Solids – Milliken (BASS-M) investigation examines the extinction characteristics of a variety of flame retardant textiles in microgravity when exposed to a controlled flame. The flame retardant behavior of treated cotton fabrics is very different from traditional flame retardant materials, but has little documented work in microgravity. The BASS-M experiment will provide data on treated cotton fabrics in microgravity and other flame resistant textiles used in clothing and fabrics in the future.

Two rodent research missions are planned during FY 2016. Rodent Research-3, sponsored by pharmaceutical company Eli Lilly and Co. and CASIS, studies molecular and physical changes in the musculoskeletal system that happen in space. Spaceflight causes a rapid loss of bone and muscle mass especially in the legs and spine, with symptoms similar to those experienced by people with muscle wasting diseases or with limited mobility on Earth. The study will assess myostatin inhibition to prevent skeletal muscle atrophy and weakness in mice exposed to long-duration spaceflight. Results expand scientists' understanding of muscle atrophy and bone loss in space, while testing an antibody that has been known to prevent muscle wasting in mice on Earth.

Rodent Research-4, sponsored by the Department of Defense (DoD) and CASIS, will focus on finding the biological interpretations of the mechanisms that prevent restoring the post-injury homeostasis and the impact of microgravity on the process. The experiment results may help to evaluate the practicality of growing complex tissues (or limbs) in spaceflight and the reason behind the negative consequences of microgravity on bone density.

Commercial service provider, NanoRacks, will deploy their NanoRacks Exposure Platform (NREP), which is capable of hosting a number of individual investigations at one time. It will support a variety of research, including air, water, and surface monitoring, avionics, communications, imaging technology, microbial populations in spacecraft, microgravity environment measurement, radiation measurements and

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|---|---|---|

shielding, robotics, small satellites, space structures, spacecraft and orbital environments, spacecraft materials, and thermal management systems. This is the first commercial platform mounted on the exterior of the ISS for commercial testing of research payloads, sensors, and electronic components in space.

CASIS continues to manage STEM programs, educational partnerships, and educational outreach initiatives using ISS National Lab-related content and plans to reach 180,000 U.S. students in FY 2016. CASIS projects manifested for launch in FY 2016 include but are not limited to stem cell research, rodent models, materials science to be performed on the new NanoRacks external platform, and additional enabling technologies to provide expanded capabilities to ISS National Lab users. CASIS also continues to support development of additional future projects in life sciences, materials development, remote sensing, and enabling technologies across private/commercial, academic, and government segments. This includes more than 160 active projects currently planned through FY 2016, including 113 from commercial industry. CASIS expects research portfolio funding to exceed its $3 million grant target. CASIS has expanded its relationship with Fortune 500 companies to include many who are considering a combination of flight projects, STEM projects, and Sponsored Programs. Through these emerging sponsored programs, CASIS plans to leverage external funding of at least $2 million.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA is planning for the delivery of the Cold Atom Laboratory (CAL), which will take advantage of the microgravity environment to create the coldest known matter in the universe—just a trillionth of a degree above absolute zero. The laboratory could enable significant discoveries in atomic physics, which would be applicable to next generation communications, navigation, timekeeping, and computing systems.

Biological and Physical Sciences will continue to enhance the existing open science pipeline to study gravity as a continuum by utilizing ground based and on-orbit ISS research. The Life Beyond low Earth orbit science initiative will seek to investigate biological systems in habitats beyond low Earth orbit. In conjunction with other ISS flight experiments, researchers will be able to explore the differences between biological adaptation and response in low Earth orbit on ISS to those changes observed in the deep space environment.

The Solidification Using a Baffle in Sealed Ampoules (SUBSA) investigations will work to refine experimental methods of crystallizing melts in microgravity with the intent of reducing fluid motion in the melt, leading to better distribution of subcomponents and the potential for improved technology used in producing semiconductor crystals.

A set of follow-on fruit fly experiments, Fruit Fly Lab 2, will be delivered to ISS and build upon the previous research by studying multiple generations of fruit flies and provide further insight into immune system and cardiovascular research.

The Advanced Plant Habitat (APH) is the largest enclosed environmentally controlled chamber designed to support commercial and fundamental plant research onboard the ISS. The APH facility is required to develop food crop production for exploration missions. The research will enable NASA to understand how to build exploration bio-regenerative life support systems with closed system ecology, mass power,

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shelf life, and storage volume. This research will also enable NASA to produce healthy food, waste management, biological stability of the habitat, and material reuse, which is critical knowledge for long-term operations of exploration systems as we move to the Proving Ground and Mars.

The Cosmic-Ray Energetics and Mass (CREAM) payload, planned for a FY 2016 launch aboard SpaceX, will measure the charges of cosmic ray particles over a broad energy range. The CREAM payload will provide important constraints on cosmic ray acceleration and propagation models currently thought to involve supernova events in the Milky Way galaxy. CREAM on the ISS may greatly reduce the statistical uncertainties, and extend prior balloon-borne CREAM measurements

Cellular biology studies planned during FY 2017 include the Tissue Regeneration – Evaluation of Inductive Agents investigation, which will study the mechanisms that restore tissues post-injury and the impact of microgravity on the process. The deliverables from this research may further help evaluate the practicality of growing complex tissues in spaceflight.

Rodent Research-5 will continue bone loss experimentation and will test a drug that is both an anabolic and anti-osteoclastic agent (based on a protein, NELL-1) in mice experiencing spaceflight-induced accelerated bone loss. In general, current therapies for osteoporosis work by preventing bone loss. Because osteoporosis affects more than 200 million people worldwide, this research has the potential to result in new innovative treatments that promote bone formation.

Astronauts will conduct the Advanced Combustion via Microgravity Experiments (ACME) project, five independent studies of gaseous flames, in the Combustion Integrated Rack (CIR). ACME's primary and secondary goals are to help improve fuel efficiency and reduce pollutant production in practical combustion on Earth, and inform spacecraft fire prevention through innovative research focused on materials flammability.

In the field of plant biology, Advanced Plant Experiments 5 (APEX-05) will utilize the Veggie facility on ISS. The investigation will focus on the growth and development of Arabidopsis thaliana seedlings in the spaceflight environment. Commonly known as Mousear Cress, Arabidopsis is an important model system for identifying genes and determining their functions, as it is short-lived, grows quickly, and has a relatively small genome. Specimens will be imaged, harvested on-orbit, preserved with a chemical fixative, and returned to the ground for post-flight evaluation.

The ISS Program has scheduled the external Multi-User System for Earth Sensing (MUSES) platform for launch on SpaceX. MUSES will simultaneously host up to four Earth observation instruments that can be changed, upgraded, and robotically serviced. Teledyne Brown Engineering is developing the Earth-imaging platform as part of its commercial space-based digital imaging business. Teledyne will operate, maintain, and sustain MUSES on a commercial basis, and provide services to hosted instruments for the ISS.

The Roll-Out Solar Array (ROSA) flight experiment will characterize an entirely new deployable solar array design in a combined space environment. The ISS-based flight experiment will measure the loads and kinematics of the (4.7 meters long by 1.7 meters wide) array during deployment. Once deployed, the flexible blanket array photovoltaic (solar cell) structural survivability will be characterized. NASA will continuously measure the photovoltaic performance throughout the duration of the experiment. In

| Formulation | Development | Operations |
|---|---|---|

addition, while deployed the array will be mechanically excited and its structural dynamics will be measured including the fundamental frequency, mode shape of the fundamental vibration, and dynamic free-decay damping.

The Neutron star Interior Composition Explorer (NICER) payload will study neutron stars by performing soft X-ray timing and spectroscopy analyses. Neutron stars are unique environments: They squeeze more than 1.4 solar masses into a city-size volume, giving rise to the highest stable densities known in the universe. The nature of matter under these conditions is a decades-old unsolved problem. By answering a long-standing astrophysics question— “How dense is a neutron star?”—NICER will provide unprecedented constraints to models describing the state of matter in extreme environments. In addition, NICER/Station Explorer for X-ray Timing and Navigation Technology (SEXTANT) will demonstrate, for the first time, real-time, on-board X-ray pulsar navigation, which is a significant milestone in the quest to establish a GPS-like navigation capability.

The Space Debris Sensor (SDS) is a calibrated impact sensor designed to directly measure the ISS orbital debris environment for two to three years. This approximately one square meter sensor will be mounted outside the ISS. SDS combines dual-layer thin films, an acoustic sensor system, a resistive grid sensor system, and sensored backstop to create a Commercial Off-The-Shelf (COTS)-based instrument that provides excellent semi-real-time impact detection and recording capability.

CASIS will bring together multiple partners from industry, academia, and other government agencies focused on common strategies to solve big cross-cutting issues through its low Earth orbit commercialization focus areas as well as its campaigns. CASIS will continue to develop working relationships with other government agencies to increase the number of stakeholders who utilize the ISS. As momentum gains in research and technology investments from prior years, CASIS expects to see an increase in tangible products, services, and research publications, especially in areas of physical and materials sciences, drug delivery/development, and disease modeling. Results from the demonstration of the NanoRacks External Payload Platform should emerge, and early indications from other enabling technology projects will follow suit. CASIS will award research grants in its portfolio well exceeding its $3 million target.

The CASIS Campaign Good Health will lead implementation of disease model reference missions to populate an open-source database, which will increase the potential for discoveries to improve life on Earth. Campaign Good Earth will continue to identify and sponsor commercial remote sensing technology demonstration flight projects for ISS. Specific emphasis will be placed on projects with the potential to share data and thus continue the development of enhanced data fusion concepts to produce unique products that improve global resource management, exploration, and climate modeling for commercial, humanitarian, and STEM application.

## Project Schedule

An increment is a period of time for ISS operations that spans from one Soyuz undock to the next Soyuz undock. There are four increments per year that consist of cargo ship arrivals and departures, as well as

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activities performed on-board, including the research performed. The table below outlines start dates of the upcoming increments to the ISS.

| Date | Significant Event |
|---|---|
| Dec 2015 | Increment 46 |
| Mar 2016 | Increment 47 |
| Jun 2016 | Increment 48 |
| Sep 2016 | Increment 49 |
| Nov 2016 | Increment 50 |
| Mar 2017 | Increment 51 |
| May 2017 | Increment 52 |
| Sep 2017 | Increment 53 |

## Project Management & Commitments

The Space, Life, and Physical Sciences Research and Applications Division (SLPSRAD) at NASA Headquarters manages Biological and Physical Sciences research. The division, working closely with the Office of the Chief Scientist, establishes the overall direction and scope, budget, and resource allocation for the project, which the NASA Centers implement, and acts as the liaison with CASIS. The ISS program office manages other ISS Research activities such as MUSS and National Laboratory enabling activities.

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| Biological and Physical Sciences | This element includes all NASA-sponsored biological and physical research. | Provider: NASA Centers, contractors, and principal investigators<br>Lead Center: Headquarters (HQ)<br>Performing Center(s): Ames Research Center (ARC), Glenn Research Center (GRC), Jet Propulsion Laboratory (JPL), Marshall Space Flight Center (MSFC), KSC<br>Cost Share Partner(s): N/A | N/A |

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| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| MUSS (includes National Laboratory enabling activities) | MUSS activities support all research on the ISS, both NASA sponsored and non-NASA sponsored. | Provider: ISS program and contractors<br>Lead Center: JSC<br>Performing Center(s): MSFC<br>Cost Share Partner(s): N/A | N/A |

## Acquisition Strategy

NASA awards contracts and grants for conducting research on the ISS. SLPSRAD manages NASA-sponsored biological and physical research. NASA selected CASIS to manage non-NASA ISS Research activities. This independent non-profit will further develop national uses of the ISS.

Peer review is the means to ensure a high-quality research program. Engaging leading members of the research community to assess the competitive merits of submitted proposals is essential to ensuring the productivity and quality of ISS Research. In FY 2016 Biological and Physical Science is releasing a request for information (RFI) as part of a stand up for the first Science Definition Team for GeneLab leading to GeneLab Open Science. In FY 2016 Biological and Physical Science will also select a Principle Investigator (PI) for a Materials Lab NRA. The Biological and Physical Science project will continue to use both traditional and open science NRAs to provide researchers, selected by peer-review, the opportunity to develop complete flight experiments and continue to allow universities to participate in flight research by involving their scientists.

NASA prioritizes ISS research based on recommendations from the National Academies and the Decadal Survey on Biological and Physical Sciences in Space. The National Academies has a committee on its Space Studies Board to provide independent advice on strategy and priorities in the physical and life sciences at NASA. In addition, there is a HEO Research Subcommittee within the NASA Advisory Council to advise NASA on the direction of basic research within HEO. Major technology demonstrations require significant cooperative funding and NASA is developing an approach for cross-agency prioritization of ISS technology initiatives.

### MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Vehicle Sustaining Engineering Contract | The Boeing Company | Houston, TX |
| Huntsville Operations Support Center | COLSA Corporation | Huntsville, AL |

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| Element | Vendor | Location (of work performance) |
|---|---|---|
| Mission Operations and Integration (MO&I) Contract | Teledyne Brown Engineering | Huntsville, AL |
| ISS National Laboratory Management Entity | CASIS | Tallahassee, FL |

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Quality | Peer Review Panel | Sep 2014 | Peer review of International Life Sciences NASA research announcement | Selection of grantees | Mar 2016 |
| Other | NASA Advisory Council | Dec 2015 | Provides independent guidance for the NASA Administrator | No formal recommendations or findings for ISS | 2016 |
| Other | NASA Aerospace Safety Advisory Panel | Dec 2015 | Provides independent assessments of safety to the NASA Administrator | No formal recommendations or findings for ISS | Feb 2016 |

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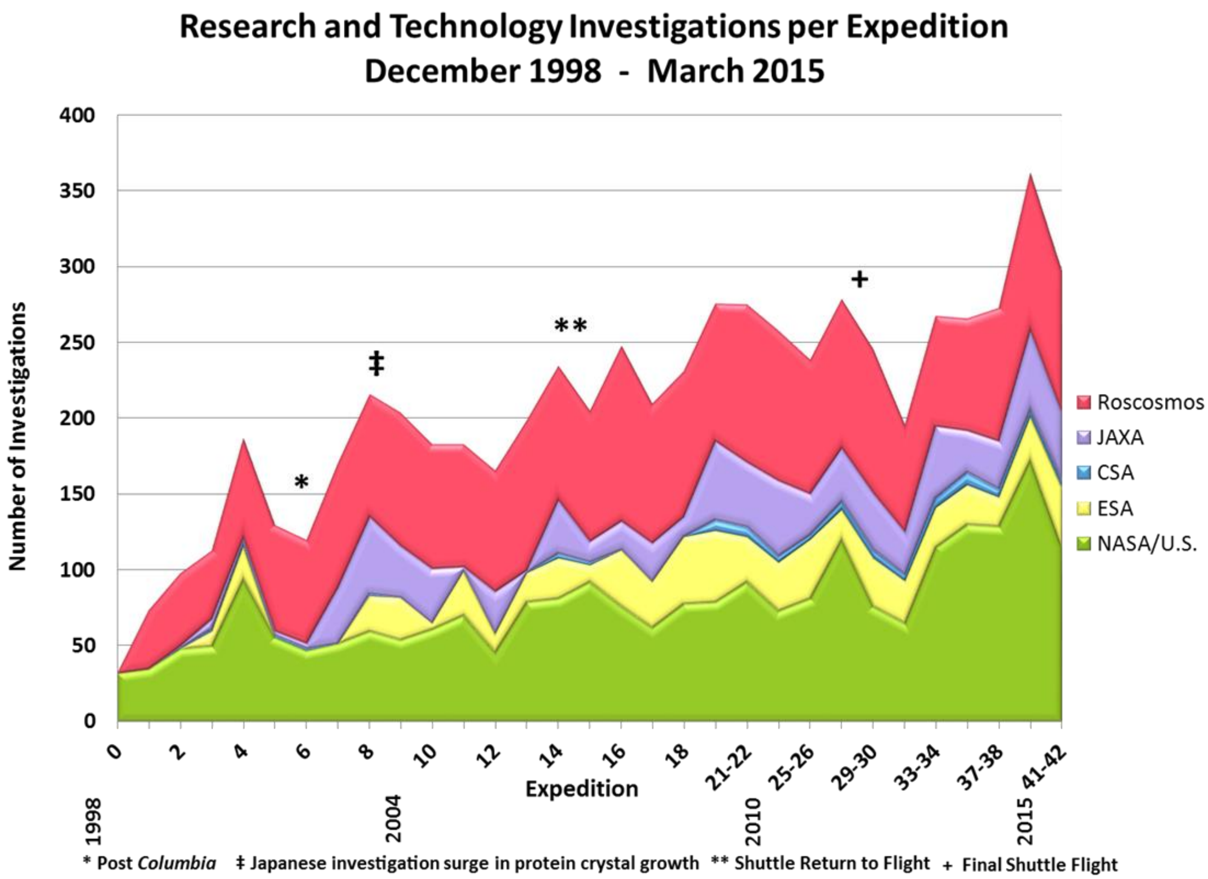
|---|---|---|

## Historical Performance

In FY 2015, NASA estimates ISS performed over 400 research and technology investigations. The chart below displays historical data, by partner agency, for research investigations performed on the ISS since 1998.




*** Post Columbia shuttle loss**

*** Post Columbia shuttle loss**

**** Shuttle Return to Flight**

**+ Final Shuttle Flight**

# SPACE TRANSPORTATION

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Crew and Cargo | 1449.0 | -- | **1572.8** | 1743.0 | 1945.6 | 2108.6 | 2177.6 |
| Commercial Crew | 805.0 | -- | **1184.8** | 731.9 | 173.1 | 35.8 | 36.3 |
| **Total Budget** | **2254.0** | -- | **2757.7** | **2475.0** | **2118.7** | **2144.4** | **2213.9** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**Launch of Orbital ATK Cygnus spacecraft on Atlas V rocket on December 16, 2015.**

The Space Transportation theme's objective is to transport U.S. astronauts and cargo safely back and forth to America's orbiting national laboratory, ISS and partner with the U.S. private sector to develop and operate safe, reliable, and affordable transportation. This newly created theme combines the CCP and the Crew and Cargo Program. Maintaining the ISS requires a fleet of vehicles and launch locations to transport astronauts, science experiments, critical supplies, and maintenance hardware; replenish propellant; and dispose of waste.

The CCP partners with the U.S. private sector to develop and operate safe, reliable, and affordable crew transportation to low Earth orbit. NASA awarded CCtCap contracts to Boeing and SpaceX in September 2014. Through its certification efforts, NASA will ensure the selected commercial transportation systems meet the agency's safety and performance requirements for transporting NASA crew to the ISS.

Within ISS Crew and Cargo Transportation, NASA purchases cargo transportation to the ISS under the Commercial Resupply Services (CRS) contracts with Orbital ATK and SpaceX and under the CRS2 contract with Orbital ATK, Sierra Nevada, and SpaceX. Crew transportation to ISS is purchased from the Russian Space Agency, Roscosmos, and from commercial providers, Boeing and SpaceX. NASA plans to continue purchasing crew transportation services from Roscosmos until a domestic capability is available. The budget also supports related activities, such as the integration work required to ensure that these visiting vehicles can safely dock or berth to ISS and hardware like the NASA docking system.

# SPACE TRANSPORTATION

## EXPLANATION OF MAJOR CHANGES IN FY 2017

While this is a new theme in FY 2017, the projects contained in this theme existed in the FY 2016 budget structure within HEOMD. CCP was previously in the Exploration account under the Commercial Spaceflight theme. The Crew and Cargo Program (formerly the ISS Crew and Cargo Transportation project) was in the Space Operations account within the ISS program.

# CREW AND CARGO

| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **1449.0** | **--** | **1572.8** | **1743.0** | **1945.6** | **2108.6** | **2177.6** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*


**The SpaceX Dragon commercial cargo craft approaches the ISS on September 23, 2014, carrying 4,885 pounds (2,216 kg) of crew supplies, hardware, experiments, and computer gear and spacewalk equipment.**

Maintaining the ISS requires a fleet of vehicles and launch locations to rotate crewmembers; replenish propellant; provide science experiments, critical supplies, and maintenance hardware; and dispose of waste. These deliveries sustain a constant supply line crucial to ISS operations and research. The Crew and Cargo program manages transportation services provided by both international partners and domestic commercial providers.

NASA purchases cargo delivery to the ISS under the CRS contracts with Orbital ATK and SpaceX. Orbital ATK launches CRS Antares missions to the ISS from the Mid-Atlantic Regional Spaceport at NASA WFF in Virginia. SpaceX launches CRS missions to the ISS from Cape Canaveral, Florida. The FY 2017 Budget supports these contracted flights, as well as future flights to provide for cargo transportation, including National Laboratory research payloads.

The Russian Space Agency, Roscosmos, currently provides ISS crew transportation. NASA plans to continue purchasing crew transportation services from Roscosmos until a domestic capability is available. The FY 2017 Budget supports these contracted Soyuz flights, as well as future domestic commercial crew flights to provide crew transportation to ISS.

The Crew and Cargo program also funds activities supporting visiting vehicles that provide transportation for the ISS, including integration activities and the NASA docking system.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

NASA previously reported this as ISS Crew and Cargo Transportation in the Space Operations account within the ISS program. NASA is now reporting it under the Space Transportation theme.

# CREW AND CARGO

| Formulation | Development | Operations |
|---|---|---|

## ACHIEVEMENTS IN FY 2015

Shortly after the Orb-3 launch on October 28, 2014, the Antares rocket carrying a Cygnus spacecraft, suffered a catastrophic anomaly that caused the destruction of the spacecraft and cargo. No injuries occurred during the mishap and no irreplaceable cargo was lost. Station operations have contingencies and other cargo missions planned which helped fill the gap from the cargo lost aboard this mission. Additionally, the SpX-7 mission was lost on June 28, 2015, when the Falcon 9 rocket carrying the Dragon spacecraft exploded after launch. No injuries occurred and critical hardware is being rebuilt. Due to advanced planning, the crew onboard the ISS were not in danger of running out of food or other necessary supplies. With NASA assistance, both commercial contractors led the investigation of their respective vehicle mishaps. Orbital ATK completed their investigation and plans to launch their next two missions on a proven Atlas rocket while they redesign and test their Antares rocket. SpaceX is nearing completion of their investigation and is implementing Falcon rocket modifications and testing. Both commercial companies are planning a return to flight in FY 2016.

Despite the loss of Orb-3, Orbital ATK completed five milestones in support of seven commercial resupply flights. Likewise, SpaceX completed fourteen milestones for performance in support of eleven commercial resupply flights, including milestones for successful completion of two flights. SpX-5 launched on January 10, 2015, delivering 5,277 pounds of supplies to the orbiting laboratory, including crew supplies, scientific research hardware, and miscellaneous supplies. The SpaceX Dragon spacecraft returned 4,151 pounds of science, hardware, and crew supplies. SpX-6 launched on April 14, 2015, delivering about 4,462 pounds of supplies to support continuing space station research experiments; and returned in May 2015 with science samples from human research, biology and biotechnology studies, physical science investigations, and education activities. This mission returned almost 3,090 pounds of science, hardware, and crew supplies.

The ISS program also supported four Russian Soyuz launches in FY 2015, providing crew transportation and rescue services to the ISS for six U.S. operating segment crewmembers.

## WORK IN PROGRESS IN FY 2016

NASA expects both Orbital ATK and SpaceX to implement plans that fulfill their contractual obligations for ISS resupply. Orbital ATK resumed cargo delivery to ISS in December 2015. SpaceX is planning to return to flight in March 2016. In total, NASA expects Orbital ATK to launch three CRS flights, and complete eleven milestones in support of seven commercial resupply flights. Orbital ATK plans to launch their first two missions on an Atlas launch vehicle from the Cape in Florida to accelerate their return to flight schedule. They plan to launch the third mission on their Antares 230 launch vehicle from Wallops, Virginia. In total, dependent upon SpaceX return to flight, NASA expects SpaceX to launch three CRS flights, and complete 13 performance milestones in support of nine commercial resupply flights. SpaceX is enhancing their Falcon launch vehicle for all future flights.

CRS2 activities will focus on selecting mission types and analyzing integration requirements. Also in FY 2016, the project will support a crew flight plan that includes approximately four Soyuz launches, carrying a total of six U.S. operating segment crewmembers to the ISS. The plan also includes four Progress launches that are not funded by NASA.

# CREW AND CARGO

| Formulation | Development | Operations |
|---|---|---|

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

The Crew and Cargo program will enable continued research and technology development by providing a stable crew and cargo flight plan. These flight plans include approximately four Soyuz launches, carrying a total of six U.S. operating segment crewmembers to ISS and commercial resupply flights to deliver research and logistics hardware. NASA expects Orbital ATK to launch two CRS flights, and complete seven performance milestones in support of four flights. SpaceX plans to launch three commercial resupply flights, and complete 14 performance milestones in support of nine flights. Orbital ATK, Sierra Nevada, and SpaceX will perform CRS2 integration milestones to support flights beginning in 2019. The plan also includes four Progress launches and one HTV launch that are not funded by NASA.

## Project Schedule

Maintaining a regular rate of cargo delivery on a mix of NASA and partner vehicles ensures the ISS can sustain nominal operations and maintenance, while allowing the program to respond to any anomalies that might occur. The table below shows the scheduled ISS flight plans for FY 2016 and FY 2017. NASA funds the SpaceX and Orbital ATK missions, as well as Soyuz seats related to U.S. operating segment crew requirements. The planned spacing of the Soyuz crew rotation flights ensures a continuous six-crew presence on the ISS, as well as smooth transitions between crews.

| Date | Significant Event |
|---|---|
| Oct 2015 | Progress 61P |
| Dec 2015 | Progress 62P |
| Dec 2015 | Orbital ATK (OA)-4 |
| Dec 2015 | Soyuz 45S |
| Mar 2016 | SpaceX (SpX)-8 |
| Mar 2016 | Progress 63P |
| Mar 2016 | OA-6 |
| Mar 2016 | Soyuz 46S |
| May 2016 | SpX-9 (under review) |
| Jun 2016 | Soyuz 47S |
| Jul 2016 | OA-5 |
| July 2016 | Progress 64P |
| Aug 2016 | SpX-10 (under review) |
| Sep 2016 | Soyuz 48S |

# CREW AND CARGO

| Formulation | Development | Operations |
|---|---|---|

| Date | Significant Event |
|---|---|
| Oct 2016 | HTV-6 |
| Oct 2016 | Progress 65P |
| Nov 2016 | Soyuz 49S |
| Dec 2016 | OA-7 (under review) |
| Jan 2017 | SpX-11 (under review) |
| Feb 2017 | Progress 66P |
| Mar 2017 | Soyuz 50S |
| Apr 2017 | SpX-12 (under review) |
| May 2017 | Progress 67P |
| Jun 2017 | Soyuz 51S |
| Jun 2017 | OA-8 |
| Aug 2017 | Progress 68P |
| Aug 2017 | SpX-13 (under review) |
| Sept 2017 | Soyuz 52S |

## Project Management & Commitments

JSC is responsible for project management of the Crew and Cargo program.

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| Crew transportation | Roscosmos will provide crew transportation to the ISS via the major contract described below until a domestic capability is available. | Provider: Roscosmos<br>Lead Center: JSC<br>Performing Center(s): N/A<br>Cost Share Partner(s): Canadian Space Agency (CSA), European Space Agency (ESA), and JAXA | N/A |

# CREW AND CARGO

| Formulation | Development | Operations |
|---|---|---|

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| Cargo transportation | Orbital ATK and SpaceX will provide cargo transportation to the ISS via the major contracts described below. JAXA will provide additional cargo transportation as part of the ISS partnership. Roscosmos will also provide nominal cargo transportation via Soyuz purchased for crew transportation. | Provider: Orbital, SpaceX, Sierra Nevada, JAXA, and Roscosmos<br>Lead Center: JSC<br>Performing Center(s): Goddard Space Flight Center (GSFC), KSC<br>Cost Share Partner(s): CSA, ESA, and JAXA | |

## Acquisition Strategy

The ISS program competitively procures all ISS cargo transportation services, excluding services obtained via barter with our international partners or nominal cargo transportation provided by Soyuz. NASA competitively awarded CRS contracts to SpaceX and Orbital on December 23, 2008, and services began in 2012. These are milestone-based, fixed-price, indefinite delivery/indefinite quantity (IDIQ) contracts. On January 14, 2016, NASA competitively awarded CRS2 contracts to Orbital ATK, Sierra Nevada, and SpaceX with cargo transportation services planned to begin in 2019. Like the current CRS contracts, CRS2 contracts are milestone-based, fixed-price IDIQ contracts. In addition, NASA has extended current CRS contracts to bridge the gap with the CRS2 procurement.

In 2006, NASA modified the Roscosmos contract to include crew transportation, rescue, and related services. The agreement is a sole source contract under Federal Acquisition Regulation (FAR) 6.302-1 (only one responsible source and no other supplies or services will satisfy Agency requirements). NASA has purchased from Roscosmos crew launches through 2018 and crew rescue and return through mid-2019. NASA will begin using domestic crew transportation services once available.

In September 2014, NASA's CCP awarded CCtCap contracts to Boeing and SpaceX. Those awards include a minimum of at least two service missions per provider, with a maximum of up to six service missions per provider. CCP will fund two service flights, called Post Certification Missions. The Crew and Cargo program will fund the remaining service flights. These crewed vehicles will provide a minimum 220 pounds of cargo as specified by the ISS program.

# CREW AND CARGO

| Formulation | Development | Operations |
|---|---|---|

## MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Crew transportation | Roscosmos | Moscow, Russia |
| Crew transportation | Boeing | Houston, TX |
| Crew transportation | SpaceX | Hawthorne, CA |
| Cargo transportation | Orbital ATK | Dulles, VA |
| Crew transportation | Sierra Nevada | Sparks, NV |
| Cargo transportation | SpaceX | Hawthorne, CA |

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Other | NASA Advisory Council | Dec 2015 | Provides independent guidance for the NASA Administrator | No formal recommendations or findings for the ISS | 2016 |
| Other | NASA Aerospace Safety Advisory Panel | Dec 2015 | Provides independent assessments of safety to the NASA Administrator | No formal recommendations or findings for the ISS | Feb 2016 |

# CREW AND CARGO

| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **805.0** | **--** | **1184.8** | **731.9** | **173.1** | **35.8** | **36.3** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**Four astronauts selected by NASA to be the first astronauts to train for test flights to space on commercial crew vehicles. Left to right: Sunita Williams, Douglas Hurley, Eric Boe, and Robert Behnken**

NASA is looking to the U.S. private sector to develop and operate safe, reliable, and affordable crew transportation to low Earth orbit, including to the ISS. Partnering with the commercial space industry for access to low Earth orbit and the ISS will bolster American leadership, reduce our current reliance on foreign providers for this service, and help stimulate the American aerospace industry.

Through the CCP, NASA provides technical and financial support to industry partners during development of their crew transportation systems, and certifies them to carry NASA astronauts to and from the ISS.

The first phase of the development effort was a series of competitively awarded Space Act Agreements (SAA), followed by Certification Products Contracts (CPC). The scope of the contracts included submittal and technical disposition of specific, early development certification products. The CPC effort allowed the partners to gain insight into NASA human space flight requirements and gave NASA early insight into partner designs and approaches.

CCP entered the final certification phase with the award of two CCtCap contracts. CCtCap requires both contractors to complete design, development, test, evaluation, and certification of an integrated Crew Transportation System (CTS). The completed transportation systems will support four NASA or NASA-sponsored crew on each flight, and provide emergency crew return, transport/return of pressurized ISS cargo, and crew safe haven while docked to the ISS.

There are numerous benefits associated with encouraging competition in the CCtCap acquisition strategy, such as controlling costs in the long term and maximizing crew safety, as reinforced in statements by the Government Accountability Office, Aerospace Safety Advisory Panel (ASAP), and NASA Office of Inspector General. The CCtCap awards represent a significant milestone in U.S. human space flight, with the goal of ending our sole reliance on foreign crew transportation to the ISS, and certification of safe,

# CREW AND CARGO

| Formulation | Development | Operations |
|---|---|---|

cost-effective U.S. commercial crew transportation systems. In addition, this approach helps stimulate growth of a new space transportation industry available to all potential customers, strengthening America's space industrial base and providing a catalyst for future business ventures to capitalize on affordable, globally competitive U.S. space access.

NASA measures partner progress against fixed-price milestones, based on performance of agreed upon entrance and success criteria. Although the content varies by partner, milestones are designed to demonstrate progress toward completing crew transportation system development, such as risk reduction testing, design reviews, hardware development, and flight tests. The Government pays for milestones only after completion. When NASA's industry partners successfully achieve all milestones, they will own and operate their completed systems.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

NASA previously reported CCP under the Exploration account. It is now in the Space Transportation theme within the Space Operations account

## ACHIEVEMENTS IN FY 2015

NASA's industry partners, Blue Origin, the Boeing Company (Boeing), Sierra Nevada Corporation (SNC), and SpaceX, made significant progress developing viable commercial crew transportation systems. NASA and Blue Origin modified their Commercial Crew Development Round 2 (CCDev2) SAA to include additional unfunded milestones, allowing them to continue working together to mature Blue Origin's crew transportation system. Blue Origin has two unfunded milestones remaining on their SAA.

NASA's follow-on initiative, CCiCap, made significant progress completing planned milestones. By the end of FY 2015, Sierra Nevada completed 10 of 11 funded milestones, including the Reaction Control System Testing – (Incremental Test #1) which will support qualification testing on the Dream Chaser spacecraft's thruster in flight-like environments. Sierra Nevada also has one unfunded milestone remaining for the Design Analysis Cycle-6 Closeout Review. SpaceX completed 12 of 15 milestones, including their pad abort test, a major developmental flight test executed at NASA's KSC in May 2015.

CCtCap development activities are progressing. Boeing has completed six of 23 development milestones, including a key Delta I – CDR milestone. After completing this milestone, Boeing was granted authority to proceed on the first Post Certification Mission (PCM). SpaceX has completed two of 18 development milestones, including an Avionics Test Bed milestone.

## WORK IN PROGRESS IN FY 2016

Sierra Nevada and SpaceX will continue to work remaining CCiCap milestones, including the Sierra Nevada engineering test article (ETA) flight testing #2 and SpaceX Dragon Primary Structure Qualification Hatch Open Test.

| Formulation | Development | Operations |
|---|---|---|

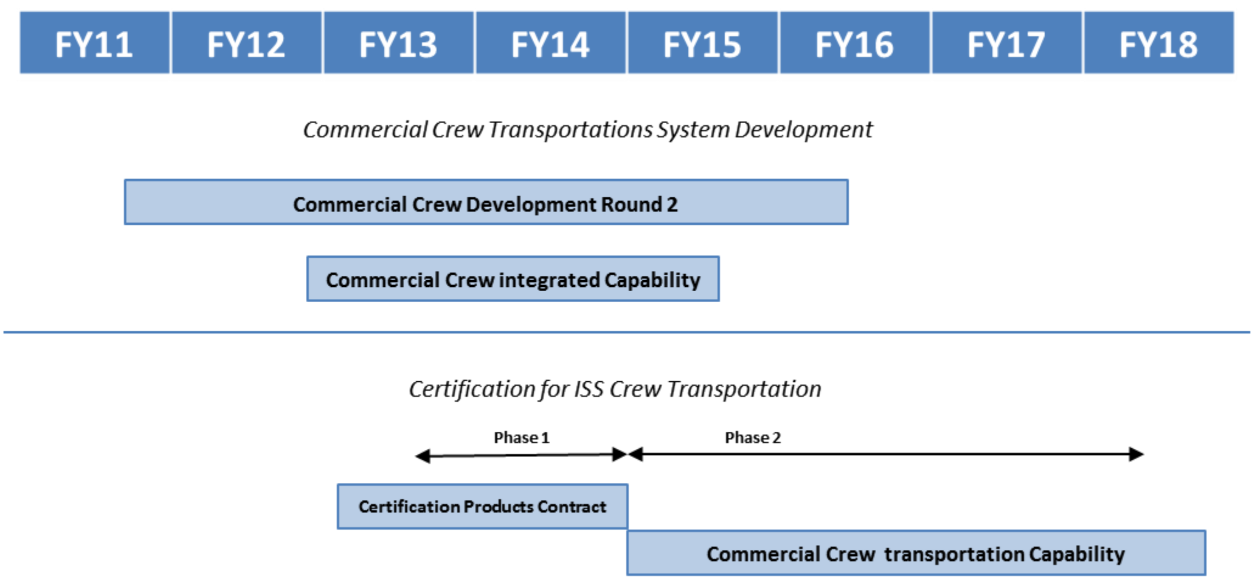
Additionally, Boeing and SpaceX will complete several CCtCap development milestones. NASA expects Boeing to complete seven out of 23 milestones, including the Flight Software Demonstration and Integrated Parachute System Drop Tests. NASA expects SpaceX to complete nine out of 18 milestones, including a key Delta CDR which will pave the way for NASA to grant authority to proceed on the first SpaceX PCM.

### KEY ACHIEVEMENTS PLANNED FOR FY 2017

Providers are on contract to complete certification by end of CY 2017. NASA expects Boeing to complete eight of 23 development milestones in FY 2017, including the Crewed Flight Test Readiness Review. NASA expects SpaceX to complete six of 18 development milestones, including the critical Flight to ISS with Crew milestone.

## Program Schedule

Progression of Commercial Crew development efforts.




## Program Management & Commitments

The HEOMD team at NASA Headquarters performs strategic management and oversight of Commercial Spaceflight, while KSC is responsible for CCP management, in collaboration with JSC. CCP partners with industry leaders, utilizing a combination of SAA and FAR-based fixed-price contracts to stimulate efforts to develop and demonstrate crew transportation capabilities.

# CREW AND CARGO

| Formulation | Development | Operations |
| --- | --- | --- |

| Program Element | Provider |
| --- | --- |
| Commercial Crew Program | Provider: Blue Origin, Boeing, Sierra Nevada, SpaceX<br>Lead Center: KSC<br>Performing Center(s): All<br>Cost Share Partner(s): Industry Partners (shown above) |

## Acquisition Strategy

CCP facilitates development of a U.S. commercial crew space transportation capability with the goal of achieving safe, reliable, and cost effective access to and from low Earth orbit and the ISS. In the early lifecycle stages, CCDev activities focused on stimulating industry efforts that successfully matured subsystems and elements of commercial crew space flight concepts, enabling technologies and capabilities. This was followed by CCDev2, which addressed new concepts to mature design and development of primary elements, such as launch vehicle or spacecraft. Subsequently, NASA continued this effort with CCiCap SAA to continue partner progress in their integrated design and development efforts. For these initial efforts, NASA utilized SAAs, which provided maximum flexibility to the provider and maximum affordability to the Government. Concurrently with CCiCap agreements, NASA awarded Certification Products Contracts to industry to begin the process of NASA certifying their crew transportation systems. The current and final stage of the acquisition lifecycle began with the award of two CCtCap contracts in September 2014 for the development, test, evaluation, and final NASA certification of a Crew Transportation System. CCtCap contracts include demonstration of crewed ISS missions and subsequent service missions, assuming sufficient budget and technical progress, and a Special Studies Services section, for special studies, tests, or analyses, as needed by NASA, to reduce Program risk. NASA used FAR-based fixed-price contracts during this phase to ensure compliance with NASA mission and safety requirements for transporting crew to and from ISS.

### MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
| --- | --- | --- |
| CCDev2 | Blue Origin | Kent, WA |
| CCtCap | Boeing | Houston, TX |
| CCiCap | Sierra Nevada | Louisville, CO |
| CCiCap/CCtCap | SpaceX | Hawthorne, CA |

# CREW AND CARGO

| Formulation | Development | Operations |
|---|---|---|

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Other | NASA Advisory Council | Dec 2015 | To provide independent guidance for the NASA Administrator | No formal recommendations or findings | 2016 |
| Other | ASAP | Dec 2015 | To provide independent assessments of safety to the NASA Administrator | ASAP recommended that the "NASA Authorization Act be reviewed with today's system's in mind" and that "mishap response procedures should be thought through, documented, and in place well before any actual flights." | Feb 2016 |
| Other | SRB | Oct 2015 | To assess funding and schedule reserve requirements, cost effectiveness during development and impacts to future sustaining operations, and efforts required for successful program implementation | SRB recommended the program proceed. | Fall 2016 |

## Historical Performance

Through FY 2015 (funded milestones only).

# CREW AND CARGO

| Formulation | Development | Operations |
|---|---|---|

| Commercial Orbital Transportation System (COTS) Partner | No. of Milestones | Total Potential Value (in $M) | No. Milestones Completed | Funding for Completed Milestones (in $M) | % Milestones Completed | % Funding Completed | Status |
|---|---|---|---|---|---|---|---|
| **SpaceX** | **40** | **396.0** | **40** | **396.0** | **100%** | **100%** | **Completed** |
| **Orbital** | **29** | **288.0** | **29** | **288.0** | **100%** | **100%** | **Completed** |
| **Rocketplane-Kistler** | **15** | **206.8** | **3** | **32.1** | **20%** | **16%** | **Terminated** |

| CCDev1 Partner | No. of Milestones | Total Potential Value (in $M) | No. Milestones Completed | Funding for Completed Milestones (in $M) | % Milestones Completed | % Funding Completed | Status |
|---|---|---|---|---|---|---|---|
| **Sierra Nevada** | **4** | **20.0** | **4** | **20.0** | **100%** | **100%** | **Completed** |
| **Boeing** | **36** | **18.0** | **36** | **18.0** | **100%** | **100%** | **Completed** |
| **Blue Origin** | **7** | **3.7** | **7** | **3.7** | **100%** | **100%** | **Completed** |
| **Paragon Space Development Corporation** | **5** | **1.4** | **5** | **1.4** | **100%** | **100%** | **Completed** |
| **United Launch Alliance** | **4** | **6.7** | **4** | **6.7** | **100%** | **100%** | **Completed** |

| CCDev2 Partner | No. of Milestones | Total Potential Value (in $M) | No. Milestones Completed | Funding for Completed Milestones (in $M) | % Milestones Completed | % Funding Completed | Status |
|---|---|---|---|---|---|---|---|
| **Sierra Nevada** | **13** | **105.6** | **13** | **105.6** | **100%** | **100%** | **Completed** |
| **Boeing** | **15** | **112.9** | **15** | **112.9** | **100%** | **100%** | **Completed** |
| **SpaceX** | **10** | **75.0** | **10** | **75.0** | **100%** | **100%** | **Completed** |
| **Blue Origin** | **10** | **22.0** | **10** | **22.0** | **100%** | **100%** | **Completed** |

| CCiCap Partner | No. of Milestones | Total Potential Value (in $M) | No. Milestones Completed | Funding for Completed Milestones (in $M) | % Milestones Completed | % Funding Completed | Status |
|---|---|---|---|---|---|---|---|
| **Sierra Nevada** | **11** | **227.5** | **10** | **219.5** | **91%** | **96%** | **Active** |
| **Boeing** | **20** | **480.0** | **20** | **480.0** | **100%** | **100%** | **Completed** |
| **SpaceX** | **15** | **460.0** | **12** | **429.8** | **80%** | **93%** | **Active** |

| CCtCap Partner | No. of Milestones | Total Potential Value (in $M)* | No. Milestones Completed | Funding for Completed Milestones (in $M) | % Milestones Completed | % Funding Completed | Status |
|---|---|---|---|---|---|---|---|
| **Boeing** | **23** | **1,976.0** | **6** | **592.8** | **26%** | **30%** | **Active** |
| **SpaceX** | **18** | **1,115.0** | **2** | **171.0** | **11%** | **15%** | **Active** |

*** Total Potential Value cited is limited to the design, development, test, and evaluation portion of the contracts. Excludes post certification mission and special studies milestones.**

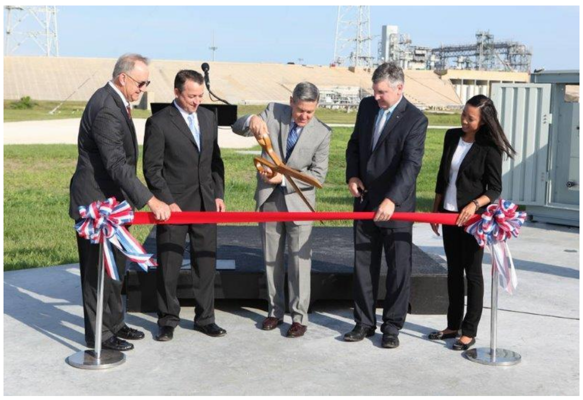
# 21ST CENTURY SPACE LAUNCH COMPLEX

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Total Budget | 35.2 | -- | 12.0 | 0.0 | 0.0 | 0.0 | 0.0 |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**Pad 39-C Deployable Launch System (DLS) ribbon cutting ceremony: The event marked the completion of DLS enabling future exploration for commercial customers.)**

In FY 2011, NASA began the 21CSLC initiative within the GSDO program to support launch infrastructure, enable future exploration of the solar system, as well as new commercial opportunities in low-Earth orbit. Its primary purpose is to modernize and transform the Florida launch and range complex at KSC, Cape Canaveral Air Force Station (CCAFS), and WFF into a more robust launch capability that could support multiple users. Beneficiaries of this activity included current and future NASA programs, other U.S. government agencies, and commercial industry.

For more information, go to http://www.nasa.gov/exploration/systems/ground.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

The 21CSLC initiative will conclude in FY 2017.

## ACHIEVEMENTS IN FY 2015

The 21CSLC initiative completed Deployable Launch System (DLS) launch site and Universal Propellant Servicing System (UPSS) at Pad 39-C. This includes site preparations within the LC-39B perimeter to support DLS verification and validation testing. Completion of the test site for the UPSS enables the development of commercial small class, launch vehicle propellant loading operations, and the ability to use actual propellants in the desired configuration. The initiative also completed MPPF construction, making the facility ready to support hazardous processing of spacecraft.

The CDRs for Eastern Range telemetry upgrades to enable antenna installation at KSC facilities were completed. The deployment of this enhanced telemetry processing system will support the Air Force Eastern Range launch campaigns. In support of this initiative, project site preparation for Kennedy Uplink Station at KSC was completed. This system can provide command/telemetry front end processing for all

KSC launch campaigns. Installation of the instrumentation shelter and the large antennae foundation allows for final system installation and activation.

21CSLC completed testing for newly automated ascent imaging trackers, providing cost efficient video tracking imagery support for all launch campaigns at the Eastern Range.

The team completed site acceptance and data certification testing for the range weather monitoring projects, including the 50-megahertz Doppler Radar Wind Profiler and the Eastern Range lightning system upgrade projects. These enhancements will greatly reduce forecasting uncertainty and improve weather monitoring across the Florida Range to support all phases of launch vehicle processing and launch operations. The Advanced Ground Systems Maintenance (AGSM) project completed a demonstration of integrated health monitoring capabilities using the Orion Exploration Flight Test – 1 (EFT-1) mission data and collaborations with KSC stakeholders. This demonstration highlighted how advanced computer simulation technology can improve the efficiency and reduce the costs of ground systems maintenance.

NASA initiated work to harden the ground systems and remote instrumentation operations at WFF's Bermuda tracking site including defining the necessary upgrade requirements, and developing the detailed design. WFF also began work on upgrading the Range Control Center (RCC), including ordering new consoles. NASA, working collaboratively as a team with the Commonwealth of Virginia, the Mid-Atlantic Regional Spaceport (MARS), and Orbital ATK, will restore medium launch capability to WFF. Pad 0A rebuild activities were completed in FY 2015 and performance testing began to support the Orbital ATK launch vehicle processing and launch.

## WORK IN PROGRESS IN FY 2016

In FY 2016, 21CSLC will complete a number of planned projects and activities. The team will finish replacing old, deteriorating cable ducts that provide critical communication connections between KSC and the Eastern Range. The team will complete facility design for eventual replacement/upgrade of the converter compressor facility, which supplies gaseous nitrogen and helium to processing and launch sites across the Florida Range. This project will accommodate the ever-increasing demand for these commodities. In addition, the team will complete a variety of range telemetry upgrades. Completion of the real-time Radio Frequency (RF) Monitoring Project will provide the improved capability to analyze all RF radiation across the Florida Range, allowing safe and efficient spacecraft processing and monitoring of launch day RF interference.

21CSLC will complete a number of infrastructure modernization projects, including refurbishing the nitrogen supply line servicing KSC and the Eastern Range launch sites. In addition, the team will complete upgrades to the multiple-object-tracking radar that provides reliable tracking of spacecraft and debris in support of range safety operations. 21CSLC will continue research into environmentally friendly coatings and corrosion preventative compounds to extend the life of structures and systems in the salt air. The 21CSLC team will also complete air handler installation in the booster fabrication facility.

WFF will complete the RCC upgrades that will improve the capabilities in the control center used to support Orbital ATK CRS launches. They will also complete the Bermuda tracking station modernization work that includes (1) transitioning to a semi-permanent site to alleviate maintenance/operational impacts from the harsh environment and (2) automating the radar systems that enhances remote tracking operations. This work will reduce annual operating costs of the WFF's Bermuda tracking site. Finally, completion of all performance testing on Pad 0A will allow Orbital ATK to return to launching CRS missions out of WFF.

### KEY ACHIEVEMENTS PLANNED FOR FY 2017

KSC will complete a number of infrastructure modernization projects, such as additional conditioning of the LC-39, crawlerway and the Banana River dredging. Dredging is required to support barge access to the Turn Basin Wharf and operations and maintenance of weather infrastructure required across the Eastern Range. One remaining project, KSC Logistics Facility, roof replacement will be funded in the Construction and Environmental Compliance and Restoration (CECR) appropriation and managed by GSDO.

The 21CSLC initiative will conclude by the end of FY 2017.

## Program Elements

The 21CSLC initiative has a multi-user focus and targets investments to develop and implement effective and efficient ground systems designs. This will meet the needs of commercial and/or government future users of the KSC and WFF. 21CSLC consists of five product lines to guide these investments as shown in the table below.

| Project/Element | Element Content |
|---|---|
| Offline Manufacturing, Processing and Recovery Systems | Repairs and upgrades systems and facilities associated with payload processing, servicing, hazardous operations, and recovery in support of commercial customers |
| Range Interface and Control Services | Develops capability for communications, range systems, customer interface systems, and advanced ground systems maintenance |
| Mission Focused Modernization | Provides multi-user facility capabilities to support a variety of vehicles, processed and launched in the horizontal or vertical configuration |
| Florida Launch Modernization Infrastructure | Modernizes power, utility and facility systems, waste management systems, and safety and security systems throughout the KSC launch infrastructure so that it can maximize the number of potential users |
| Environmental Remediation and Technologies | Ensures energy conservation, environmental planning and regulatory requirements, natural resource mitigation, and environmental research, including materials replacement and technology development are being addressed |

## Program Schedule

The following table highlights the major 21CSLC and WFF activities with their estimated completion timeframes.

# 21ST CENTURY SPACE LAUNCH COMPLEX

| Date | Significant Event |
|---|---|
| Oct 2013 | Pad B Flame Trench refurbishment design complete |
| May 2014 | Eastern Range Lightning System upgrade complete |
| Nov 2014 | Advanced Ground System Maintenance Interface to End-to-End Command and Control System demonstration |
| Sep 2015 | 50-megahertz Doppler project complete |
| May 2016 | Crawler Transport jacking, equalization and leveling system cylinders complete |
| Jan 2016 | Replace Island Primary Electrical Feeder complete |
| Jul 2017 | Banana River Dredging |
| Jun 2017 | Range Interface and Control System |

## Program Management & Commitments

The GSDO manage both EGS and 21CSLC activities at KSC. GSDO manages customer requirements between SLS, Orion, and multiple other Government and commercial users to ensure implementation of cost-effective, synergistic design solutions. GSFC manages WFF activities.

The following table addresses the various elements within 21CSLC, lead and participating Centers, and any cost share partners.

| Program Element | Provider |
|---|---|
| Offline Manufacturing, Processing and Recovery Systems | Provider: 21CSLC<br>Lead Center: KSC<br>Performing Center(s): KSC<br>Cost Share Partner(s): N/A |
| Range Interface and Control Services | Provider: 21CSLC<br>Lead Center: KSC<br>Performing Center(s): ARC, JPL, GRC, GSFC<br>Cost Share Partner(s): U.S. Air Force (USAF) |
| Mission Focused Modernization | Provider: 21CSLC<br>Lead Center: KSC<br>Performing Center(s): KSC<br>Cost Share Partner(s): N/A |

# 21ST CENTURY SPACE LAUNCH COMPLEX

| Program Element | Provider |
| --- | --- |
| Florida Launch Modernization Infrastructure | Provider: 21CSLC<br>Lead Center: KSC<br>Performing Center(s): KSC<br>Cost Share Partner(s): USAF |
| Environmental Remediation and Technologies | Provider: 21CSLC<br>Lead Center: KSC<br>Performing Center(s): KSC<br>Cost Share Partner(s): N/A |
| WFF | Provider: 21CSLC<br>Lead Center: GSFC<br>Performing Center(s): WFF<br>Cost Share Partner(s): N/A |

## Acquisition Strategy

To maintain flexibility and maximize affordability, NASA serves as its own prime contractor for implementation of the 21CSLC and WFF activities. GSDO executes customer ground infrastructure and processing requirements by leveraging Center and programmatic contracts at KSC. GSFC executes the projects at WFF in the same manner. GSDO also uses pre-qualified IDIQ contractors for routine work while exercising full and open competition for larger or more specialized projects. Firm-fixed-price contracting provides maximum incentive for contractors to control costs, and imposes a minimum administrative burden upon the contracting parties.

### MAJOR CONTRACTS/AWARDS

21CSLC includes activities of varying size and content. Several of the activities are within the scope of existing Center contracts. Competitively bidding of a contract occurs only if the activity is not within the scope of an existing agreement or contract.

| Element | Vendor | Location (of work performance) |
| --- | --- | --- |
| 50 megahertz Doppler Radar Wind Profiler | QinetiQ, North America | KSC |
| Jacking, equalization and leveling cylinder (crawler transporter) | QinetiQ, North America | KSC |
| 50 megahertz Doppler Radar Wind Profiler | QinetiQ, North America | KSC |

# 21ST CENTURY SPACE LAUNCH COMPLEX

## INDEPENDENT REVIEWS

The 21CSLC activity is not required to manage with the same formal independent reviews NASA requires for traditional programs and projects. In accordance with Agency policy, initiatives and activities of this nature are not subject to the independent review process. In addition, the total funding for 21CSLC falls below the threshold required to initiate a review. The 21CSLC activity was a product of the 2011 National Space Policy Launch Infrastructure and Modernization Plan (NSTP PPD - 4 Implementation Action # 6). NASA and the USAF 45th Space Wing (45SW) conduct periodic reviews of completed studies to define requirements for improvements and fund range modernization. The 45SW and KSC hold quarterly reviews to provide governance for the investments and track development and progress toward realizing operational capabilities. WFF identifies 21CSLC candidate development projects to NASA HQ who approve these projects and fund them directly.

# SPACE COMMUNICATIONS AND NAVIGATION

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Space Communications Networks | 516.3 | -- | **526.0** | 532.1 | 476.3 | 421.9 | 465.0 |
| Space Communications Support | 62.8 | -- | **86.3** | 84.0 | 121.3 | 154.5 | 149.6 |
| **Total Budget** | **579.1** | -- | **612.4** | **616.1** | **597.6** | **576.4** | **614.6** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**The surface reflector of the DSS-36 antenna at the Canberra Deep Space Communication Complex, Australia is slowly lifted into position atop the alidade. Weighing 138 tons (276000 lbs.), the reflector could only be lifted on a day with very little wind.**

The SCaN program provides mission-critical communications and navigation services required by all NASA spaceflight missions. These missions range from high altitude balloons at the edge of Earth's atmosphere to science satellites in low Earth orbit and the most distant manmade object, Voyager 1, which left the solar system, and is now over 12 billion miles from our planet. For all of these missions, SCaN retrieves science and spacecraft health data, uploads commands, and sends data to individual control centers. Navigation services determine precisely where a satellite is and where it is going to enable course changes, interpret science data, and position the spacecraft for communication opportunities.

Without SCaN services to move data and commands between spacecraft and Earth, customer missions and space hardware worth tens of billions of dollars would be little more than orbital debris. A communications or navigation failure on the spacecraft or in SCaN network systems could result in complete loss of a mission. SCaN provides secure, reliable, and adaptable communication services to NASA internal customers, as well as external customers who rely on these space communications capabilities on a daily basis.

SCaN customers include the Hubble Space Telescope (Hubble) in Earth orbit, the Curiosity rover on the surface of Mars, and the New Horizons robotic mission reporting science data after its successful flyby of the dwarf planet Pluto, and its moon, Charon. The program supports the ISS as well as its commercial and international servicing vehicles, and will support commercial crew providers and the future launches of the SLS and Orion crew vehicle. SCaN will also provide the vital communications link with the James Webb Space Telescope after launch in late 2018. Additionally, SCaN provides services to foreign governments, international partners, and non-NASA US missions on a reimbursable basis.

SCaN provides customer missions with the required space communications and navigation. Customer requirements include mission orbit, navigation needs, data rate, and the frequency of communication opportunities. SCaN networks and the customer spacecraft must match technical parameters, such as radio spectrum frequency, data coding, modulation scheme, polarization, and error correction. SCaN supports new spacecraft that are increasingly powerful, complex, and capable of acquiring ever increasing amounts of mission data, as well as missions launched over 30 years ago that are still returning valuable science data. In addition, SCaN tracks and characterizes near Earth objects within nine million miles, and determines their orbits for use by the Science Mission Directorate's (SMD's) Planetary Science Division for collision avoidance with Earth. SCaN is working to upgrade this capability to a distance of 42 million miles, which increases the time to develop viable solutions for orbital collision.

SCaN's three communications networks, Space, Near Earth, and Deep Space, provide critical services to customer missions. The Space Network communicates with missions in Earth orbit, and provides constant communication with the ISS. In the future, it will also support commercial crew and Orion missions. The Near Earth Network (NEN) communicates with suborbital missions and missions in low Earth orbit, highly elliptical Earth orbit, and some lunar orbits. DSN communicates with the most distant missions, such as interplanetary probes.

These three networks require maintenance, replenishment, modernization, and capacity expansion to ensure service for existing and planned missions. SCaN also purchases ground communications links from the NASA Communication Services Office to move data between ground stations, NASA centers, and mission operation and data centers. SCaN is continuing the systems analysis to determine how to effectively manage the networks as one entity, providing efficiency of operations and cost savings.

The TDRS Replenishment project purchased three third-generation TDRS spacecraft for the Space Network that will ensure adequate services to customers into the early 2020s. Two are currently on orbit, and one has finished development and is in storage awaiting launch, scheduled for the first quarter of FY 2018.

The SGSS project is replacing aging ground hardware and data systems in the Space Network. These ground systems operate the TDRS fleet and route customer mission data between TDRS and the ground station.

Space Communications Support provides functions to efficiently integrate and plan current and future network capabilities to meet customer mission needs while reducing costs. These include systems engineering, architecture planning, communications data standards, technology development, testbeds for future capabilities, and radio frequency spectrum management.

For more information, go to http://www.nasa.gov/scan.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

As part of a recent SGSS evaluation, NASA determined that SGSS is more in line with a sustainment project of the existing Space Network rather than a separate development project. The evaluation determined SGSS is a sustainment project since it is maintaining the current Space Network by replacing aging and outdated equipment and systems at the ground terminals. As such, SGSS is a level of effort project, which will reported as part of Space Communications Networks.

# SPACE COMMUNICATIONS NETWORKS

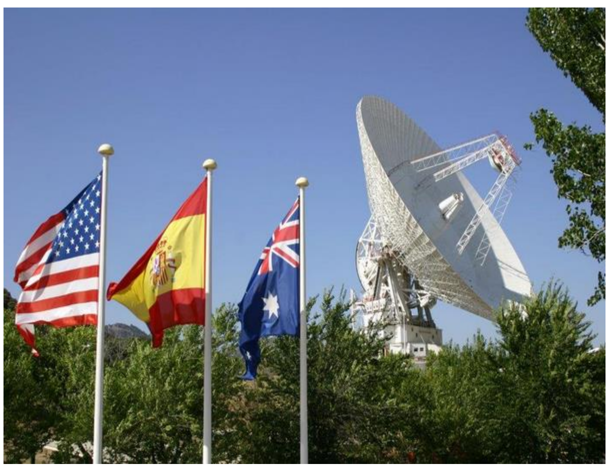
| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **516.3** | **--** | **526.0** | **532.1** | **476.3** | **421.9** | **465.0** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**This 70-meter antenna, located in Madrid Spain, is part of NASA's DSN. DSN provides support to NASA and other missions, and has facilities located around the world.**

The SCaN program manages NASA's three space communications networks: the Space Network, NEN, and DSN. These networks provide tracking and data transmission for NASA and its customers. Each network has a different set of customer requirements for spacecraft orbit, signal strength, and real-time coverage, and each requires maintenance, modernization, and capacity expansion in order to continue providing proficiency at or above 95 percent for over 90 customer missions.

NASA's space communications networks provide ongoing services to Agency and customer missions, averaging about 438 tracking passes per day. Without these capabilities, customer missions like Hubble, ISS, New Horizons, Mars Exploration Rover—Opportunity, and Voyager would not be able to provide key science data that could help unlock mysteries of science and knowledge about our universe, and would eventually fail.

The Space Network provides continuous global coverage to NASA missions in low Earth orbit, during vehicle launch, and ascent phase. It is the primary U.S. communications link to the ISS, as well as for ground and balloon research in remote locations, such as the South Pole. The Space Network consists of NASA's TDRS System (TDRSS) of communications satellites in geosynchronous orbit, a set of space-to-ground link terminals at NASA's White Sands Complex, New Mexico, remote space-to-ground terminals in Guam, and at Blossom Point, Maryland. Customer missions communicate with the TDRS spacecraft, which relays signals to and from the ground terminals. Maintaining and modernizing this critical network is one of the Agency's top priorities. To accomplish this, SCaN's SGSS project works to replace obsolete ground terminal equipment that is nearing the end of its life cycle, with current technology that will improve reliability and cost efficiency.

NASA's current TDRS fleet consists of four first-generation satellites placed into orbit 20 to 25 years ago, three second-generation satellites that have provided services for more than a decade, and two new

# SPACE COMMUNICATIONS NETWORKS

| Formulation | Development | Operations |
|---|---|---|

third-generation satellites. The four original first-generation satellites are well past their expected life cycles and are showing signs of age-related battery and electronics failures. Three new third-generation satellites, TDRS-K, -L, and -M, are prepared to, or have joined, the on-orbit fleet. TDRS-K and -L are operating, and TDRS-M is in storage with a planned launch in 2017.

The NEN provides space communications to missions in low Earth, geosynchronous, lunar, and highly elliptical Earth orbits, as well as from certain suborbital launch locations. The NASA owned network's ground stations are located at White Sands, NM; U.S. McMurdo Antarctic Station; Wallops Flight Facility, Chincoteague, VA; and University of Alaska, Fairbanks, Alaska. The network also purchases services from commercial providers in Hawaii, Norway, Sweden, Singapore, South Africa, Australia, and Chile.

The DSN provides space communications capabilities to missions from outside low Earth orbit to those beyond the edge of the solar system, such as the Voyager spacecraft. The network's ground stations are spaced approximately 120 degrees apart on the globe in Spain, Australia, and California, to maintain continuous communications with distant spacecraft as the Earth rotates. NASA owns these stations, and the DSN Project Office at JPL manages operations, maintenance, and upgrades for this network.

The DAEP modernizes and upgrades the DSN's ground stations to enhance capacity, improve flexibility to support customer missions, and reduce operations and maintenance costs. Much of the network's hardware is over 31 years old and has become difficult and costly to maintain. This is true of antenna structures; exotic electronics, such as high-power transmitters; cryogenically cooled low noise amplifiers; and support elements. Construction efforts, such as new 34-meter antennas, use Construction of Facilities funds appropriated in NASA's Construction and Environmental Compliance and Remediation account.

The SGSS project is replacing outdated and expensive equipment and systems at the ground terminals. SGSS is a ground sustainment project that will incrementally upgrade the current space network. New equipment and software, based on current technology, will be more reliable and cost less to maintain and operate. Due to the operational nature of the networks, NASA performs sustainment activities while communications are ongoing with no loss of service. The SGSS concept and architecture will bring the Space Network into the digital age, providing decades of reliable service. NASA's approach to SGSS will reduce the cost of operations and maintenance by eliminating major periodic refurbishments or high-cost upgrades while continuing to increase capability and robustness.

The SCaN program purchases services from the NASA Communications Services Office (CSO) to move information between the three space communications network ground stations and NASA centers, customer mission operations, and data centers. The CSO is a centralized commercial service that provides point-to-point communication services between ground sites. NASA's Office of the Chief Information Officer manages the CSO service.

For more information, go to http://www.nasa.gov/scan.

# SPACE COMMUNICATIONS NETWORKS

| Formulation | Development | Operations |
|---|---|---|

## EXPLANATION OF MAJOR CHANGES IN FY 2017

As part of a recent SGSS evaluation, NASA determined that SGSS is more in line with a sustainment project of the existing Space Network rather than a separate development project. The evaluation determined SGSS is a sustainment project since it is maintaining the current Space Network by replacing aging and outdated equipment and systems at the ground terminals. As such, SGSS is a level of effort project which will reported as part of Space Communications Networks.

## ACHIEVEMENTS IN FY 2015

During the fiscal year, the Space Network supported over 30 missions, with over 178,000 hours of tracking and more than 160,000 passes. The Space Network successfully completed TDRS-12 testing on January 25, 2015, and placed it into service on February 12. SCaN networks provided launch to splash-down communication of the first Exploration Flight Test 1 launch on the Delta IV rocket, provided space communication for the HTV-5 spacecraft docking to ISS, and impounded and delivered appropriate data from the SpaceX/Dragon SpX-7 launch mishap.

NASA continued to replenish networks to resolve ongoing obsolescent equipment. By continuing to upgrade and replace equipment, NASA will ensure necessary deep space communications required for its current and future deep space missions. Upgrades include antenna drive units and radomes in Guam, chillers and electrical equipment at White Sands, and White Sands ground equipment to meet ISS requirements to provide 600 Mbps Ku-band service. The DSN modernization program continued to upgrade and replace existing antennas at its complexes. The network tracking sites include Canberra, Australia; Madrid, Spain; and, Goldstone, California. Part of NASA's long-term plan is to upgrade and repurpose or replace earlier generation 70-meter antennas with 34-meter arrayed antennas. The construction of the DSN DSS-36 (34-meter) antenna in Canberra, Australia, progressed with an expected operational date of October 2016. The DSN successfully supported downloading scientific data from the New Horizons spacecraft since its dramatic July 2015 flight past the icy dwarf planet Pluto and its moon Charon, and plans to continue to support science data downloads through FY 2016.

The SCaN program completed the CDR for Launch Communication Stations at KSC and downrange in Bermuda. These sites are needed to support key human spaceflight programs such as Orion's EM-1 and future Exploration Missions. The SCaN program signed an agreement with the SMD for use of the Bermuda station in July 2015.

Capping more than a year's effort, SGSS completed a major step in software integration and system development activities; integrated software is a major deliverable for SGSS and drives the ground system performance. The project continues building on early ground terminal functionality and successfully conducted demonstration of TDRS Spacecraft Telemetry Tracking and Control and user service functions.

# SPACE COMMUNICATIONS NETWORKS

| Formulation | Development | Operations |
|---|---|---|

## WORK IN PROGRESS IN FY 2016

The three space communications networks will provide a level of service similar to those provided in FY 2014 and FY 2015. This includes over 160,000 tracking passes, totaling more than 178,000 hours, while maintaining an extremely high level of proficiency (approximately 99.95 percent or higher) well above the 95 percent required by the SCaN Program Commitment Agreement.

In 2015, SCaN completed the TDRS-M spacecraft on time, which was prepared for storage on September 30, 2015. On behalf of SCaN, HEOMD LSP awarded a contract for a launch vehicle on October 30, 2015 with the planned launch for TDRS-M in 2017. With both TDRS-K and TDRS-L accepted and on orbit, along with TDRS-M launch scheduled in 2017, the SCaN program’s Space Network will have adequate capacity for its expected mission set until the second-generation TDRS begin retiring in the early 2020s.

DAEP work planned at the MDSCC includes construction of two new 34-meter antennas, DSS-56 and DSS-53, which will replace the 70-meter antenna located at this site. The DSN also plans to finalize the operational readiness for the DSS-36 (34-meter) in October 2016. These new antennas will transmit and receive across a wide range of radio frequencies for deep space communication with interplanetary robotic spacecraft to provide required capabilities for the expected growth of deep space missions launching over the next decade.

The Space Network is modernizing new ground station hardware and software under the SGSS project. Near the end of FY 2016, the Space Network will have its first opportunity to begin testing on new SGSS equipment. The SGSS project is continuing to develop and deploy a ground system that will enable the Space Network to maintain safe, reliable, and cost efficient operations for the next several decades. This includes software coding, hardware integration, and testing for SGSS. In addition, work continues with subsystem development, integration, and testing. This is an important step towards achieving the new, modernized Space Network, which will enable state of the art communications capability with the ISS, SLS, Orion, and other orbiting spacecraft well into the 21st century.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

The three major goals for SCaN networks include: 1) removing TDRS-M spacecraft from storage and delivering it to a launch service provider at KSC in preparation for launch in 2017; 2) continuing development of new SGSS ground station hardware and software; and 3) continuing DAEP work involving site, foundation, and pedestal work for DSS-56 (34-meter) and 53 (34-meter) antennas at MDSCC. The DSN also plans to enter DSS-36 (34-meter) into operation in October 2016.

All three networks will continue to identify and implement methodologies, processes, and equipment intended to help shape and achieve improvements over historical operational efficiencies and goals. System engineering plans and conceptual design options are carried out by engaging representatives from all three networks, and will play an active role for communication and data transmission planning for future robotic and human spaceflight missions, including NASA Orion and SLS vehicle development. SGSS will continue development, integration, and test activities associated with new ground station hardware and software.

# SPACE COMMUNICATIONS NETWORKS

| Formulation | Development | Operations |
|---|---|---|

## Project Schedule

| Date | Significant Event |
|---|---|
| Q1 FY 2015 | DSS-35 antenna acceptance into the DSN for operational use |
| Q4 FY 2015 | TDRS-M completed development and placed in storage |
| Q1 FY 2016 | Initial construction of DSS-53 |
| Q3 FY 2016 | Initial construction of DSS-56 |
| Q1 FY 2017 | DSS-36 antenna acceptance into the DSN for operational use |
| FY 2017/Q1 FY 2018 | Launch TDRS-M Spacecraft |

## Project Management & Commitments

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| Space Network | Communication and navigation services to customer missions in low Earth orbit and launch vehicles | Provider: Space Network Project Office<br>Lead Center: GSFC<br>Performing Center(s): N/A<br>Cost Share Partner(s): Non-NASA customers | N/A |
| NEN | Communication and navigation services to customer missions in low Earth, highly elliptical, and lunar orbits | Provider: NEN Project Office<br>Lead Center: GSFC<br>Performing Center(s): N/A<br>Cost Share Partner(s): Non-NASA customers | N/A |
| DSN | Communication and navigation services to customer missions in deep space | Provider: DSN Project Office<br>Lead Center: JPL<br>Performing Center(s): N/A<br>Cost Share Partner(s): Non-NASA customers | N/A |
| NASA CSO | SCaN purchases ground communication services for NISN | Provider: CSO, through NASA Chief Information Officer<br>Lead Center: NASA HQ<br>Performing Center(s): MSFC, GSFC<br>Cost Share Partner(s): N/A | N/A |

# SPACE COMMUNICATIONS NETWORKS

| Formulation | Development | Operations |
|---|---|---|

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| TDRS Replenishment | Purchase third-generation TDRS-K, -L, and -M to maintain Space Network communications services to customer missions into the 2020s | Provider: Boeing Space Systems<br>Lead Center: GSFC<br>Performing Center(s): N/A<br>Cost Share Partners: Other U.S. government agencies | Development cost reduced. TDRS-M added to purchase |
| SGSS | Replace outdated and deteriorating ground systems at Space Network ground terminals | Provider: SGSS Project Office<br>Lead Center: GSFC<br>Performing Center(s): N/A<br>Cost Share Partner(s): Non-NASA U.S. government partners | N/A |

## Acquisition Strategy

The major acquisitions for the networks are in place. NASA uses reimbursable, international, and barter agreements, as well as competitive procurements. NASA's JPL provides the management of the DSN.

### MAJOR CONTRACTS/AWARDS

NASA awarded the TDRS-M launch vehicle contract on October 30, 2015.

| Element | Vendor | Location (of work performance) |
|---|---|---|
| DSN | JPL | Pasadena, CA |
| Space Network Operations | Exelis | McLean, VA |
| NEN Operations | Exelis | McLean, VA |
| TDRS Replenishment, including TDRS-K, -L, and -M and modifications to Space Network ground systems to support these spacecraft | Boeing Space Systems | El Segundo, CA |
| TDRS-M Launch Vehicle | United Launch Services, LLC | Centennial, CO |
| SGSS | General Dynamics Mission Systems | Scottsdale, AZ |

# SPACE COMMUNICATIONS NETWORKS

| Formulation | Development | Operations |
|---|---|---|

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| TDRS-L ORR/FRR | Standing Review Board (SRB) | Nov 2013 | Assess if all systems are operationally ready for the spacecraft and if the spacecraft is ready for flight | Passed | LRD |
| TDRS-L Launch Readiness Date (LRD) | Flight Board | Jan 2014 | Assess if all systems are ready for launch | Passed | On-orbit Acceptance |
| TDRS-L On-Orbit Acceptance Review | SRB | Jun 2014 | Assess if TDRS-L is ready to be accepted by the Government | Passed | N/A |
| NASA Office of Inspector General (OIG) Review | NASA OIG | Ongoing | Assess SCaN program and projects | Ongoing | Space Network and DSN complete; NEN in process |

# SPACE COMMUNICATIONS SUPPORT

| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **62.8** | **--** | **86.3** | **84.0** | **121.3** | **154.5** | **149.6** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**Laser Communication Relay Demonstration (LCRD) Modem Team successfully demonstrated optical communication between LCRD Ground Modem #1 and the Massachusetts Institute of Technology (MIT) Lincoln Laboratory Optical Terminal Verification Testbed Modem. LCRD will be NASA's first use of a commercially hosted payload for technology demonstration. The demonstration is a major first step towards commercializing laser communication across deep space.**

NASA's SCaN program has a long history of exceptional service reliability and proficiency, but that success does not come easily. Maintaining a high level of performance requires the extensive planning, management, and technology efforts of the Space Communications Support project.

SCaN's architecture planning and systems engineering ensure customer missions operate together with NASA networks by defining technical services, capacity, and performance requirements to eliminate duplication across networks, minimize mission-unique requirements, and lower development and operations costs.

Like the technological advances that have so radically changed the way we communicate with each other, evolving space communication systems can transform future NASA mission capabilities, in ways we can only imagine today. SCaN's technology development effort invests in leading edge communications technology, and enables, improves, and matures available technologies to build systems and capabilities for ground-based and spacecraft communication and navigation use.

Operating in space requires significant international coordination. SCaN's standards development and management activity maintains a portfolio of internationally agreed upon interoperability standards that enable joint space missions with other nations. SCaN also promotes new technologies, and provides technical leaders and domain experts who ensure appropriate space communication standards are available to NASA missions.

# SPACE COMMUNICATIONS SUPPORT

| Formulation | Development | Operations |
|---|---|---|

Amid soaring demand for wireless broadband, such as 3G and 4G mobile services, radio frequency spectrum management has become increasingly critical to the world's spacefaring nations. SCaN coordinates nationally and internationally to protect radio frequencies critical to NASA space missions. The SCaN team ensures all Agency activities comply with rules and regulations applicable to the electromagnetic spectrum, and advocates for radio frequencies to remain available for NASA use.

Just as the Global Positioning System (GPS) receiver in your car or smartphone uses satellites and ground stations to pinpoint your location on the Earth, GPS provides precision positioning, navigation, and timing for vehicles in space. This allows NASA to maximize spacecraft autonomy, and enables precise space flight methods, such as formation flying. SCaN manages NASA's policy on GPS use and plays a major role on the international front, ensuring compatibility and interoperability among spacefaring nations, promoting common definitions and specifications, and mitigating threats to the GPS spectrum.

For more information, go to https://www.nasa.gov/scan.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None

## ACHIEVEMENTS IN FY 2015

NASA's vision for the future SCaN network architecture is to build and maintain a scalable and integrated infrastructure that provides cost effective space communications services at order-of-magnitude higher data rates to enable NASA's science and exploration missions. This infrastructure can readily evolve to accommodate new and changing technologies and will preserve current capabilities to support user mission critical events and emergencies.

As part of this evolution, SCaN conducted the System Definition Review (SDR) for the Phase 2 unified network. The results of the SDR added maturity to the Phase one design concept and improved the overall unified network. SCaN also completed the initial studies for the next generation Earth (TDRSS) and Mars relay capabilities.

SCaN continued to make progress towards developing the Laser Communication Relay Demonstration (LCRD), jointly funded by SCaN and NASA's STMD. The 1.25-gigabit-per-second data rate ground modem successfully demonstrated interoperability with the testbed at MIT Lincoln Laboratory. LCRD will be a major first step towards commercializing laser communications for both near Earth and in deep space. The project has had multiple commercial operators express significant interest to use the payload during its full demonstration beginning in 2019.

The SCaN TestBed continued operations externally on ISS and has logged over 2,500 hours of operations since launch in 2012. The SCaN TestBed developed several important technologies advancing the future of SCaN networks. The project demonstrated the capability of transmission at nearly 1 gigabit-per-second data rate over Ka-band, winning a NASA Silver Achievement Medal for their efforts. Separate work on the Digital Video Broadcast Second Generation transmission from space demonstrated improved

# SPACE COMMUNICATIONS SUPPORT

| Formulation | Development | Operations |
|---|---|---|

downlink to a ground station showing improved quality video reception. In the future, commercial standards derived from the SCaN developed technologies will help NASA networks be more interoperable, increase network throughput, and enhance spectrum efficiency by allowing greater amounts of data transmitted in a given bandwidth, and adjusting data rates according to radio frequency link conditions.

SCaN continued developing space communication standards, lowering space missions' risks and operation costs while enabling joint space missions with other nations. In 2015, SCaN standards developed consensus with international agencies agreeing on optical communication standards for near earth and deep space missions clearing the path for future multi-national collaboration.

In collaboration with HEOMD's Advanced Exploration Systems and NASA's SMD, SCaN continued demonstrating antenna array uplink with the high resolution Ka-Band Objects Observation and Monitoring (KaBOOM) system. The KaBOOM is designed to better track asteroids, comets, and orbital debris. NASA hopes KaBOOM will significantly improve image resolution and enable radar images of near earth objects to see details as small as five centimeters, or the size of a golf ball. Today, NASA's best radar images are limited to 400 centimeters, or about the size of a family garage.

## WORK IN PROGRESS IN FY 2016

Using the results of recently completed next generation SCaN systems studies, SCaN is developing a top-level architecture strategy and concept and is reviewing it with stakeholders. This strategy and architecture concept will provide the basis for the first steps in the next generation SCaN capabilities. Additionally, work continues on defining the top level capabilities for the next-generation Earth and Mars relays with the goal of incorporating those results into the definition of the 2025 SCaN architecture.

The LCRD project will take delivery of flight hardware, including the space switching unit, controller electronics, and commercialized subcomponents of optical modules from vendors in New Mexico, Colorado, New York, and Massachusetts. With application to both commercial and NASA Operations, SCaN will complete Preliminary Design Review (PDR) and Key Decision Point C for LCRD. GSFC will build and integrate the LCRD flight modems in FY 2016 for delivery to the project in FY 2017. Set to fly as a hosted payload, this technology demonstration will provide an order of magnitude leap in communications capability for future TDRS satellites, other government agencies, and commercial space communication providers.

SCaN TestBed on ISS will focus on developing variable and adaptive radio techniques making SCaN's networks more autonomous and responsive. Leveraging the Digital Video Broadcast Second Generation, the project will develop a closed-loop system to detect interference and adjust frequencies to reduce error rates. SCaN TestBed will also perform research towards the autonomous development of a spacecraft-initiated service request. In addition, SCaN is continuing to study placing an optical communication user terminal on the Japanese space agency module on ISS in 2020. This terminal will work with LCRD to demonstrate laser-based technologies. This new terminal will be based on a commercialized, next generation design with significantly lower size, weight, and power than the current state-of-the-art LCRD modem.

# SPACE COMMUNICATIONS SUPPORT

| Formulation | Development | Operations |
| --- | --- | --- |

SCaN is continuing research into Disruption Tolerant Networking (DTN) techniques, allowing science data to be downlinked to many space and ground assets and re-assembled safely and securely at a final destination. Development of this seamless technology will make NASA's networks more efficient while reducing complexity and increasing resiliency and will introduce similar concepts of internet operations space communications.

SCaN is also funding advanced optical communications technology for deep space in partnership with SMD and STMD. The Deep Space Optical Communications effort currently underway at JPL will advance the maturity level of several components needed for deep space by the end of FY 2016. The Deep Space Atomic Clock is scheduled for launch in September 2016 and will revolutionize precise timing necessary for spacecraft accuracy and operations. In 2016, SCaN standards team will continue developing a universal space link protocol to replace four space link communication protocols with one, for human and robotic missions.

SCaN contributed to the agenda planning and actively participated in the International Telecommunication Union's World Radio communication Conference in November 2015. SCaN represented NASA with the State Department and other Federal agencies in national and international negotiations on key items related to NASA's spectrum requirements.

KaBOOM will build on FY 2015 accomplishments with plans to combine the signals from three antennas at Goldstone, California, and correct for atmospheric twinkling in real time, maximizing the antennas' power. Additionally, KaBOOM will use three low cost antennas at KSC and demonstrate the system can image small near-Earth objects. Finally, the techniques demonstrated at Goldstone may be used in an attempt to save the STEREO-B spacecraft that has not communicated with ground stations since October.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

Efforts will continue to advance NASA's space network architecture, concept of operations, requirements and cost estimating to mature implementation plans for the future unified SCaN network. SCaN will work to insert new technologies into near-Earth and DSN systems for phase 3. The support provided by SCaN includes support system acquisition, maturing optical communications, space internetworking, cognitive radios, and other technologies needed to enable future missions.

As part of SCaN's new technology development, LCRD plans to complete its CDR, and initiate hardware fabrication to support a late CY 2019 launch readiness date. Deep Space Optical Communications will provide a Technology Readiness Level (TRL) 6 validation and demonstration of the flight laser transceiver and ground support equipment. In addition, operations of the Deep Space Atomic Clock will greatly increase precise timing and accuracy during its flight demonstration.

To push new frontiers in communication and future network operations, the SCaN TestBed will demonstrate signal classification techniques for Galileo navigation protocols with the European Space Agency. In addition, the TestBed will evaluate cognitive engine demonstration with Digital Video Broadcast Second Generation and coding protocol selection. The Standards team will develop specifications for a wireless local area network protocol, supporting communications for both human and

# SPACE COMMUNICATIONS SUPPORT

| Formulation | Development | Operations |
|---|---|---|

robotic activities on planetary surfaces. KaBOOM project plans to transform its system at KSC to a communications and high power radar system.

SCaN will continue working with the National Telecommunications and Information Administration Policy and Plans Steering Group to help identify Federal spectrum for auction and repurpose for commercial mobile broadband. This effort, sponsored by Presidential Initiative, intends to identify 500 MHz of spectrum for mobile broadband use within 10 years, while ensuring critical Federal operations are not adversely impacted.

## Project Schedule

| Date | Significant Event |
|---|---|
| Q2 FY 2015 | SCaN Program Phase 2 SDR |
| Q1 FY 2016 | World Radio telecommunications Conference |
| Q3 FY 2016 | Deep Space Atomic Clock ships to Commercial Spacecraft Host (Surrey) |
| Q4 FY 2016 | Deep Space Atomic Clock Launch |
| Q4 FY 2017 | LCRD User Terminal on ISS PDR |
| Q4 FY 2017 | All component designs of the Deep Space Optical Communications system are flight-qualified by ground testing at TRL 6 |

## Project Management & Commitments

The SCaN Program Office at NASA Headquarters manages Space Communications Support functions.

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| Space Communications Support | Provides critical communication and navigation architecture planning, systems engineering, technology development, standards development and management, spectrum management, and policy and strategic communications for NASA | Provider: NASA<br>Responsible Center: HQ | N/A |

# SPACE COMMUNICATIONS SUPPORT

| Formulation | Development | Operations |
| --- | --- | --- |

## Acquisition Strategy

Space Communications Support functions use multiple small contracted efforts, most of which are support services functions.

### MAJOR CONTRACTS/AWARDS

Space Communications Support does not have any major contracts planned at this time.

# HUMAN SPACE FLIGHT OPERATIONS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **99.7** | **--** | **128.3** | **130.4** | **139.9** | **142.0** | **143.8** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**Scott Kelly inside a Soyuz simulator at the Gagarin Cosmonaut Training Center located at Star City, Russia preparing for his one-year mission and twin study starting March 2015.**

Through more than 54 years of human space exploration, NASA has faced challenges that led to advances in technology, produced new industries, and nurtured our relationships with other nations. As in the earliest days of Project Mercury, the very core of human space exploration is the crew. Today, from anywhere with an Internet connection, people on Earth can watch NASA's skilled astronauts in high definition, engaged in daily life on the ISS. The Human Space Flight Operations (HSFO) program supports the training, readiness, and health of crewmembers before, during, and after each space flight mission to the ISS. All crews on board the Space Station have undergone rigorous preparation, which is critical to mission success. Within the HSFO program, the Space Flight Crew Operations (SFCO) element provides astronaut selection and training while the Crew Health and Safety (CHS) element manages all aspects of astronaut crew health.

To prepare for the next step in human space exploration, the Agency is developing the transportation system that will carry crew to destinations beyond Earth's orbit. NASA must also prepare the human system for living and working for extended periods in the hostile environment of space. As astronauts travel further from Earth, many different issues will arise and need investigating. What health risks will astronauts face and how are they resolved? What type of training will crews need to prepare for months of travel in the harsh space environment? How will they deal with medical emergencies or technical anomalies when Earth is no longer within reach? CHS, in collaboration with NASA's Office of Chief Health and Medical Officer and HEOMD's Human Research Program (HRP), answers these questions and others to ensure crew health, safety, and mission success. SFCO and CHS are responsible for astronaut training, readiness, and health while HRP funds development of human health and performance countermeasures, knowledge, and technologies that enable safe, reliable, and productive human space exploration.

# HUMAN SPACE FLIGHT OPERATIONS

## EXPLANATION OF MAJOR CHANGES IN FY 2017

Astronaut candidate class selections moved from FY 2016, FY 2018, and FY 2020 to FY 2017, FY 2019, and FY 2021 to better align with ISS and Exploration manifest requirements. HSFO added the Aerosciences Ground Test Capability, which establishes centralized funding to support mission access to test facilities throughout the year, enabling mission testing, advancements of capabilities and tools, and innovation

## ACHIEVEMENTS IN FY 2015

SFCO provided a trained astronaut for one-year stay on ISS and three trained astronauts for five-month stays on ISS. SFCO also selected four astronauts to begin training for crewed test flight of first human U.S. commercial crew vehicle.

During the year, CHS convened research and clinical advisory panels with HRP comprised of external experts to determine crew health management strategies for visual impairment and intracranial pressure (VIIP), radiation risks, and intervertebral disk damage. CHS completed career radiation exposure analysis for a 12-month ISS mission in 2017 and provided critical analysis to evaluate the risk of carbon dioxide exposure aboard the ISS resulting in further lowering of operational levels. Monitoring carbon dioxide levels on board ISS is important to assure optimal crew health and behavioral health and performance. CHS made improvements to Information Technology medical data systems and completed improvements to future astronaut selection criteria and training processes. Improvements will result in better handling of medical data requests and screening future astronaut candidates. Lastly, CHS developed testing schedules needed to conduct medical and psychological clearances of astronaut candidates during selection cycles.

## WORK IN PROGRESS IN FY 2016

In FY 2016, SFCO will begin training astronauts in support of the first human commercial space vehicle to ISS. SFCO plans to partner with the ISS program in the Revolutionize ISS for Science and Exploration effort as core ISS processes are streamlined to support primary customers' payloads and research.

CHS will provide clinical certification and mission support for active astronauts and physical, behavioral, and reconditioning health support for returning ISS expeditions. CHS plans to standardize astronaut occupational space suit exposure tracking during operations and training exercises. In addition, CHS will provide real time support to the ISS 12-month crew for on-orbit health monitoring; exercise regimen management; behavioral health support; and post-landing health evaluation, reconditioning, and monitoring. CHS will support the Agency's Chief Health and Medical Officer on long-term improvement in crew occupational health and maintenance. Further CHS will deploy data visualization tools to promote analysis in support of operational, clinical, and risk management decision-making.

Since the early days of human space flight, NASA has accumulated and archived crew health and safety data for use by the human health clinical research community. During FY 2016, CHS Data Management and epidemiology teams will update crew health data and analytics to guide CHS-hosted working groups. This will result in increased quantity and quality of crew health and safety data to research and clinical communities.

# HUMAN SPACE FLIGHT OPERATIONS

In FY 2016, HRP will transition the Integrated Medical Model 4.0 to CHS. This updated risk prediction tool will provide new capabilities, such as randomizing crew health events throughout a mission and quantifying the impact of partial or alternative medical treatment options against adverse health outcomes. An updated Radiation Risk Model, employing a multiple exposure modeling capability will continue to advance towards becoming operational. This enhancement refines radiation risk projections to astronauts, and takes into account the dose effects of multiple space flight missions as well as non-space flight radiation exposure.

CHS will continue the lifetime surveillance program, monitoring retired astronauts for adverse health outcomes related to their service with NASA. Data collection under this surveillance program broadens our understanding of the long-term health risks of human space flight.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

In FY 2017, SFCO will continue to provide trained astronauts for crewed test flight of the first commercial crew vehicle, as well as conduct interviews and select a new astronaut candidate class.

CHS will test and evaluate candidates for the next astronaut class selection in FY 2017. CHS will continue physical, behavioral, return, and reconditioning health support for returning ISS Expeditions and provide crew health support for astronauts training to fly on commercial crew vehicles. CHS will continue providing clinical certification and mission support for active astronauts who are either departing or returning to the ISS. CHS will continue to accumulate and archive crew health and safety data for use by the human health clinical research community.

CHS will update the Astronaut Radiation Exposure and Analysis Database to incorporate multiple exposure data. CHS will continue to monitor HRP progress towards developing mitigation strategies for astronaut exposure and protection from solar and galactic radiation during space missions. Mitigation of solar and galactic radiation beyond the protection of the Earth’s atmosphere is an occupational and safety concern particularly for long duration human spaceflight. CHS will also continue to track and monitor other work in development by HRP.

# Program Elements

## SPACE FLIGHT CREW OPERATIONS (SFCO)

SFCO provides trained astronauts for all NASA human space flight efforts. Responsibilities include directing and managing flight crew activities, selecting astronaut candidates, recommending flight crew assignments, and operating program support aircraft; most notably, a fleet of T-38 aircraft for high performance astronaut space flight readiness training. In addition, SFCO ensures that space flight readiness training requirements continue to support ongoing ISS operations, planned exploration, and commercial development.

SFCO is responsible for astronaut training, consistent with recommendations reported in the National Academies’ report, Preparing for the High Frontier, (NRC, 2011). As part of its annual planning, the project ensures all astronaut training is consistent with ISS and Exploration manifest requirements. The minimum manifest requirement is based upon the number of spacecraft seats U.S. astronauts must fill in the next five years to support the human space flight manifest and includes ISS via Soyuz, as well as projected Commercial Crew and Orion/SLS development flights. Today, it takes three years from the decision to select a new astronaut class until the process is completed. New astronauts must complete 12-18 months of training for eligibility and then 30 months of ISS training before a new astronaut reaches the ISS. Astronaut training activities, overseen by SFCO, include launch and landing operations, ability to respond in an emergency/high-stress environment, high performance aircraft operations skills, flight vehicle maintenance, payload and science experiment operator skills, extravehicular activities, Russian language skills, robotics (including free-flier capture), and ISS systems knowledge.

## CREW HEALTH AND SAFETY (CHS)

CHS enables healthy and productive crew during all phases of space flight missions, implements a comprehensive astronaut occupational health care program, and works to prevent and mitigate negative long-term health consequences from exposure to the space flight environment. Using HRP research findings, CHS implements changes to astronaut occupational health protocols to ensure crew health and safety. CHS also medically assesses astronaut candidates as part of the selection process. In this collaboration, HRP concentrates on the research aspects of crew health, whereas CHS focuses on implementing the research results into occupational health protocols. As research continues on ISS through 2024, CHS actively seeks new ways of doing business, including collaborative opportunities with other Federal agencies and academia.

CHS is also responsible for maintaining the health of active astronauts during non-mission periods, focusing on three aspects of health care: preventive care, risk factor management, and long-term health monitoring. CHS integrates and coordinates information relevant to the human health before, during, and after space flight. CHS documents and assesses all emerging health risks, such as VIIP syndrome. CHS has continued to collaborate with a number of non-NASA organizations to include the National Academies for the risk decisions associated with long duration and exploration missions.

# HUMAN SPACE FLIGHT OPERATIONS

## Program Schedule

| Date | Significant Event |
|---|---|
| Mar 2015 | NASA Astronaut Scott Kelly and Russian Cosmonaut Mikhail Korniyenko began the first-ever one-year mission aboard the ISS |
| Jul 2015 | Four astronauts selected to begin training for crewed test flight of the first human U.S. commercial space flight vehicle |
| Jul 2015 | Astronaut Class of 2013 completed their astronaut candidate training and became eligible for assignment to space flight missions |
| Oct 2015 | Reduce space flight readiness training aircraft (T-38) operational fleet size from 19 to 18 |
| Oct 2015 | Begin selection process for the Astronaut Class of 2017 |
| Dec 2015 | Retire NASA's reduced-gravity aircraft (C-9), ending NASA's microgravity flight services capability |
| Aug 2017 | Astronaut Class of 2017 will arrive at JSC to begin new astronaut training (14 selections expected) |

## Program Management & Commitments

| Program Element | Provider |
|---|---|
| SFCO will provide trained astronauts for all U.S. human space flight endeavors and bring experienced astronauts' expertise to help resolve operations or development issues. | Provider: SFCO<br>Lead Center: JSC<br>Performing Center(s): JSC<br>Cost Share Partner(s): None |
| CHS will assess and maintain the health of astronauts before, during, and post flight. | Provider: CHS<br>Lead Center: JSC<br>Performing Center(s): JSC<br>Cost Share Partner(s): None |

## Acquisition Strategy

The section below identifies the current contract(s) that support SFCO and CHS.

# HUMAN SPACE FLIGHT OPERATIONS

## MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
|---|---|---|
| Aircraft Maintenance and Modification Program | DynCorp International LLC | Ellington Field, Houston, TX, El Paso, TX |
| Bioastronautics Contract | Wyle Integrated Science and Engineering Group | Houston, TX |

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Independent Assessment | National Academies | Sep 2011 | Evaluate plans relative to the role and size of SFCO activities following the Space Shuttle retirement and completion of the assembly of the ISS including the astronaut corps' fleet of training aircraft. | The National Academies' conclusions largely reinforced NASA decision making and approach to crew training. | N/A |
| Performance | National Academies | Jul 2012 | At the request of NASA, a National Academies committee reviewed NASA HRP's Scientific Merit Assessment Processes for directed research. | The committee found that the scientific merit assessment process used by the HRP for directed research is scientifically rigorous and is similar to the processes and merit criteria used by many other Federal agencies and organizations. | N/A |
| Performance | National Academies | Jul 2012 | The National Academies' Committee on Aerospace Medicine and the Medicine of Extreme Environments (CAMMEE) reviewed what ethical and policy considerations are involved when exposures/risks are uncertain and exposures may exceed current standards. | The CAMMEE provided a report to NASA March 2014, recommending a framework for ethical decision-making. | N/A |

# LAUNCH SERVICES

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | 80.6 | -- | 87.2 | 89.1 | 89.1 | 90.0 | 91.4 |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**NASA's MMS observatories are processed for launch in a clean room at the Astrotech Space Operations facility in Titusville, Florida in preparation for launch in 2015. NASA SMD will investigate how the Sun's and Earth's magnetic fields transfer energy from one to the other in a process known as magnetic reconnection.**

Utilizing commercially available domestic launch services, LSP has provided affordable and reliable space access for science exploration, communication, weather forecasting, and technology development for over 17 years. NASA science and technology missions need these launch services to get into space and begin their critical work.

Acting as a technical expert, LSP matches NASA and other civil sector government spacecraft with commercially available launch services through a competitive process. Once the right launch vehicle is selected, the program purchases a "ride to space" for the customer. Starting with pre-mission planning and continuing through the spacecraft's post-launch phase, LSP works with the customer and launch vehicle provider to maximize mission success. LSP provides NASA missions with access to a dependable and secure Earth-to-space bridge, launching spacecraft to orbit our planet or to venture into deep space.

LSP acquires and manages launch services, and ensures pricing is consistent and fair. Through launch-related contracts, the program provides the launch service, pre-launch spacecraft processing facility support, and communications and telemetry during ascent for their customers. Additionally, LSP offers insight into the commercial launch vehicle industry, tracks lessons learned to identify and mitigate risks for future managed launches, and certifies the readiness of new commercial launch vehicles for NASA and other civil sector agency spacecraft. The program also conducts engineering analyses and other technical tasks to maximize launch success for every NASA payload.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None

# LAUNCH SERVICES

## ACHIEVEMENTS IN FY 2015

Two major payloads successfully launched utilizing LSP-acquired services:

| Launch Date/Location | Launch Vehicle | Payload | Customer | Mission Objectives |
|---|---|---|---|---|
| Jan 2015<br>Vandenberg Air Force Base | Delta II | SMAP | NASA SMD | Provide global measurements of soil moisture and its freeze/thaw state to enhance understanding of processes to link the water, energy, and carbon cycles, and extend the capabilities of weather and climate prediction models. |
| Mar 2015<br>CCAFS | Atlas V | MMS | NASA SMD | Utilize four spacecraft flying in formation to investigate how the Sun's and Earth's magnetic fields connect and disconnect, explosively transferring energy from one to the other in a process is important everywhere in the universe, known as magnetic reconnection. |

*LSP's customers own and manage the payload mission objectives described above.*

In addition, LSP continued efforts to expand the selection of available launch vehicles, working across industry to support commercial space sector growth by providing competitive opportunities to U.S. providers.

The program acquired launch services for three future science missions:

| Launch Date/Location | Launch Vehicle | Payload | Customer | Mission Objectives |
|---|---|---|---|---|
| Jun 2017<br>Kwajalein | Pegasus XL | ICON | NASA SMD | A suite of instruments designed to explore the mechanisms controlling the environmental conditions in space and how they are modified by weather on the planet. |
| Aug 2017<br>CCAFS | Falcon 9 v1.1 | TESS | NASA SMD | Space telescope designed to survey the brightest stars near the Earth. Utilize an array of cameras to perform an all-sky survey to study the mass, size, density and orbit of a large cohort of small planets, including a sample of rocky worlds in the habitable zones of their host stars. |

# LAUNCH SERVICES

| Launch Date/Location | Launch Vehicle | Payload | Customer | Mission Objectives |
|---|---|---|---|---|
| Jul 2018<br>CCAFS | Delta IV Heavy | SPP | NASA SMD | Flying into the Sun's atmosphere (or corona), for the first time. Coming closer to the Sun than any previous spacecraft, SPP will employ a combination of in situ measurements and imaging to achieve the mission's primary scientific goal: to understand how the Sun's corona is heated and how the solar wind is accelerated. |

*LSP's customers own and manage the payload mission objectives described above.*

LSP completed the certification effort for the Falcon 9 v1.1 in May 2015 and certified it as a medium risk launch vehicle as defined in NASA policy, with a single certification exception. SpaceX is working to correct the issue that caused the exception and LSP has put appropriate mitigation steps in place to mitigate the technical risk. Certification is vital because it enhances NASA's understanding of commercially built launch vehicles and enables LSP to better judge launch risks. Certification enhances competition as it results in multiple qualified, launch vehicles and launch providers, which in turn promotes cost control.

In July 2015, LSP was tasked to serve in the NASA Independent Review Team (IRT) function, as part of the SpaceX Falcon 9 v1.1 SpX-7 accident investigation and return to flight. LSP independently reviewed the launch vehicle telemetry and created a detailed millisecond event timeline; reviewed the SpaceX-led Accident Investigation Team's (AIT's) findings and corrective actions; developed and analyzed additional alternative failure scenarios; conducted independent testing; and made its own independent accident related findings and recommendations. LSP completed their IRT function with their out brief to the NASA Flight Planning Board on December 4, 2015.

NASA and LSP continued to partner with several universities to launch small research satellites through the Educational Launch of Nanosatellites project and the CubeSat Launch Initiative, which provides rideshare opportunities for small satellite payloads to fly on upcoming launches when space is available. These partnerships provide educational opportunities for students in science, technology, engineering, and mathematics disciplines, thereby strengthening the Nation's future workforce. To date, NASA has selected CubeSats from 29 states across the United States, with 41 launched and 14 manifested on NASA, National Reconnaissance Office, U.S. Air Force, and Commercial missions.

As CubeSats continued to play an increasingly larger role at NASA, LSP began work to develop a new Venture Class Launch Service (VCLS). VCLS will serve as an alternative to the current rideshare approach and will foster a commercial launch market dedicated solely to flying small satellite payloads. NASA awarded three VCLS contracts on September 30, 2015 to Firefly Space Systems Inc., Rocket Lab USA, and Virgin Galactic LLC, with the first demonstration launch scheduled for spring 2018.

In addition, LSP provided facility support, ground support equipment, communication and video capabilities, and computer modeling of the Orion vehicle's guidance, navigation, and control system for EFT-1. LSP also provided Payload Processing and Hangar AE support, as well as targeted technical assessments, to the National Oceanic and Atmospheric Administration Deep Space Climate Observatory (DSCOVR) mission.

# LAUNCH SERVICES

## WORK IN PROGRESS IN FY 2016

LSP provides expertise and active launch mission management for over 40 NASA scientific spacecraft missions in various stages of development. In FY 2016, the program continues to acquire new launch services for future NASA missions. One science mission is planned for launch in FY 2016.

| Launch Date/Location | Launch Vehicle | Payload | Customer | Mission Objectives |
|---|---|---|---|---|
| Sep 2016<br>CCAFS | Atlas V | Origins, Spectral Interpretation, Resource Identification, and Security - Regolith Explorer (OSIRIS-REx) | NASA SMD | Visit an asteroid in 2016, perform six months of surface mapping, and use a robotic arm to collect samples to return to Earth. This data helps explain our solar system's formation and how life began, as well as improve understanding of asteroids that could impact our planet. |

*LSP's customers own and manage the payload mission objectives described above.*

While NASA had planned to launch Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) in FY 2016, the launch date is currently under review and will not occur in FY 2016.

Along with full end-to-end launch service management, the program continues to offer advisory support, expertise, and knowledge to NASA programs and projects utilizing launch services not procured and managed by LSP. The program is currently providing these advisory services to several missions, including:

- ISS CRS missions;
- CCP; and
- SMD's Gravity Recovery and Climate Experiment Follow-On (GRACE-FO), Webb, and NASA-Indian Space Research Organization Synthetic Aperture Radar (NISAR) missions

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

LSP is planning six civil sector missions for launch:

| Launch Date | Launch Vehicle | Mission Name | Customer | Mission Objectives |
|---|---|---|---|---|
| Oct 2016 | Pegasus XL | CYGNSS | NASA SMD | Measure ocean surface winds throughout the life cycle of tropical storms and hurricanes, to facilitate better weather forecasting. |

# LAUNCH SERVICES

| Launch Date | Launch Vehicle | Mission Name | Customer | Mission Objectives |
|---|---|---|---|---|
| Oct 2016 | Atlas V | GOES-R | NOAA, NASA SMD | First in a series of next generation geostationary weather satellites that will provide continuous imagery and atmospheric measurements of Earth's Western Hemisphere and space weather monitoring. |
| Nov 2016 | Delta II | JPSS (3c) | NASA SMD | Gather data on a wide range of Earth's properties, including the atmosphere, clouds, radiation budget, clear-air land and water surfaces, and sea surface temperature. |
| May 2017 | Atlas V | GOES -S | NOAA, NASA SMD | Follow on mission in a series of satellites that will provide continuous imagery and atmospheric measurements of Earth's Western Hemisphere and space weather monitoring. |
| Jun 2017 | Pegasus XL | ICON | NASA SMD | A suite of instruments designed to explore the mechanisms controlling the environmental conditions in space and how they are modified by weather on the planet. |
| Aug 2017 | Falcon 9 | TESS | NASA SMD | Space telescope designed to survey the brightest stars near the Earth. The telescope will utilize an array of cameras to perform an all-sky survey to study the mass, size, density and orbit of a large cohort of small planets, including a sample of rocky worlds in the habitable zones of their host stars. |

*LSP's customers own and manage the payload mission objectives described above.*

LSP will continue launch service acquisition activities necessary to support NASA and other approved government missions, and provide launch related mission support to over 40 NASA scientific spacecraft missions in various development phases.

## Program Management & Commitments

| Program Element | Provider |
|---|---|
| Expendable Launch Vehicle (ELV) Launch Services | Provider: United Launch Services (ULS), Orbital ATK, SpaceX, Lockheed Martin Space Systems<br>Lead Center: KSC<br>Performing Center(s): KSC<br>Cost Share Partner(s): N/A |

# Acquisition Strategy

LSP put a unique acquisition strategy in place under the original NASA Launch Services (NLS) contracts for procuring ELV launch services from domestic commercial launch service suppliers. To meet the needs of science and technology customers who typically spend three to seven years developing a spacecraft mission, NASA created a contractual approach providing multiple competitive launch service options to cover small, medium, and intermediate-sized missions. The follow-on contract mechanism, known as NLS II has similar contract features, such as not-to-exceed prices; indefinite delivery/indefinite quantity contract terms; and firm-fixed price, competitive, launch service task-order-based acquisitions. The NLS II ordering period expires in June 2020. To keep competition fresh and encourage new launch capability development on these 10-year contracts, NASA provides annual opportunities to U.S. industry to add new commercial launch service providers and/or launch vehicles to the active contract.

LSP is also able to contract separately from the NLS contract mechanism if such an approach is necessary to meet a particular mission or customer need. For instance, for the SPP mission funded by NASA SMD, the launch service was competed outside and separate from the NLS II contract due to the special needs of that mission. In addition, the VCLS awards for very small launch vehicles was conducted outside and separate from the NLS II contract in order to provide more flexibility to the new small-class launch providers

NASA has also made efforts to provide a complete launch service, including payload processing at the launch site. LSP uses firm-fixed price indefinite delivery/indefinite quantity contracts for commercial payload processing capabilities on both the east and west coasts. The Payload Processing Facility contracts ordering period expires in December 2017.

## MAJOR CONTRACTS/AWARDS

| Element | Vendor | Location (of work performance) |
|---|---|---|
| SPP | ULS, LLC | Centennial, CO |
| Venture Class | Virgin Galactic<br>Firefly Space Systems<br>Rocket Lab USA | Long Beach, CA<br>Cedar Park, TX<br>Los Angeles, CA |
| NLS-II-A | Lockheed Martin Space Systems | Denver, CO |
| NLS-II-U | ULS, LLC | Centennial, CO |
| NLS-II-S | SpaceX | Hawthorne, CA |
| NLS-II-O | Orbital ATK Corporation | Dulles, VA |
| Payload Processing Facility | Astrotech Space Operations | Titusville, FL |
| Payload Processing Facility | Astrotech Space Operations | Vandenberg Air Force Base, CA |
| Integrated Processing Facility | Spaceport Systems International | Vandenberg Air Force Base, CA |
| Expendable Launch Vehicle Integrated Support (ELVIS) 2 | a.i. Solutions, Inc. | Lanham, MD |

## INDEPENDENT REVIEWS

NASA has scheduled the LSP Program Implementation Review (PIR) in CY 2019.

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| PIR | SRB | May 2014 | Life Cycle Review | Board found LSP is a successful program with a strong technical and management team representing NASA's core competency, demonstrating exceptional performance with a 97.4 percent launch success record. Standing Review Board recommended continuation of LSP operations as currently performed. | 2019 |

## Historical Performance

LSP managed ELV Missions from inception through FY 2015.

| Launch Vehicle Configuration | Provider | Number of Launches | Successful Launches | Unsuccessful Launches |
|---|---|---|---|---|
| Athena | Lockheed Martin/Alliant Techsystems | 1 | 1 | 0 |
| Atlas IIA | Lockheed Martin | 5 | 5 | 0 |
| Atlas IIAS | Lockheed Martin | 1 | 1 | 0 |
| Atlas V | Lockheed Martin<br>ULS | 2<br>12 | 2<br>12 | 0<br>0 |
| Delta II | Boeing Launch Services<br>ULS | 27<br>14 | 27<br>14 | 0<br>0 |
| Pegasus Hybrid | OSC | 1 | 1 | 0 |
| Pegasus XL | OSC | 13 | 13 | 0 |
| Taurus XL | OSC | 2 | 0 | 2 |
| Titan II | Lockheed Martin | 3 | 3 | 0 |

# ROCKET PROPULSION TEST

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Total Budget | 44.4 | -- | 47.6 | 47.6 | 47.6 | 48.0 | 48.8 |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**On January 9, 2015, RPT performed the first RS-25 engine on the A-1 test stand at SSC in Mississippi. This successful 300-second test began a multi-year testing effort required to prepare the engine for use on the SLS Core Booster Stage..**

Development and test of rocket propulsion systems is foundational to spaceflight. Whether the payload is a robotic science experiment or a crewed mission, the propulsion system must be safe, reliable, and accurate. A rigorous engine test program is a critical component of any rocket propulsion development activity.

NASA's Rocket Propulsion Test (RPT) program maintains and manages a wide range of facilities capable of ground testing rocket engines and components under controlled conditions. This world-class test infrastructure includes facilities located across the United States, and provides a single entry point for any user of the rocket test stands. The program retains a skilled workforce, capable of performing tests on all modern day rockets including supporting complex rocket engine developments. RPT program evaluates customer test requirements and desired outcomes, minimizing test time and costs. The program manages facility usage and eliminates redundant capability by closing, consolidating, and streamlining NASA's rocket test facilities.

RPT is NASA's implementing authority for rocket propulsion testing. The program approves and provides direction on test assignments, capital improvements, and facility modernization and refurbishment. RPT integrates multi-site test activities, identifies and protects core capabilities, and develops advanced testing technologies.

The Agency has designated RPT as the NASA representative for the National Rocket Propulsion Test Alliance (NRPTA)—an inter-agency collaboration with DoD to facilitate efficient and effective use of the federal government's rocket propulsion test capabilities. The RPT Program Manager serves as a co-chair of the NRPTA Senior Steering Group, and appoints NASA's alliance co-chair. This position is a rotational appointment chosen from primary center representatives of RPT's management board.

For additional programmatic information, go to http://rockettest.nasa.gov.

# ROCKET PROPULSION TEST

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## ACHIEVEMENTS IN FY 2015

During FY 2015, the RPT program safely performed 453 tests of rocket engines and components at various levels of thrust. Hot fire test time totaled 10,062 seconds and 29.5 days of thermal vacuum testing.

On January 9, 2015, RPT performed the first RS-25 engine test on SSC A-1 test stand. This successful 300-second test began a multi-year effort necessary to use the engine on SLS Core Booster Stage, required to support EM-1 and other exploration goals. Other activities included testing for SpaceX, Aerojet Rocketdyne, and numerous internal research and development projects such as NASA Morpheus/Multi-Use Thruster. SSC personnel also began preparations on the E-1 Cell 1 test stand to support the USAF Hydrocarbon Boost program, a critical effort to assist the DoD objective of replacing the RD-180 engine used in the Atlas 5 launch vehicle. In addition to the USAF hydrocarbon program, NASA entered into a reimbursable agreement with Aerojet Rocketdyne to prepare the E-1 Cell 2 test stand to test subscale hydrocarbon components at SSC. In addition, RPT continued refurbishing and repair activities for critical infrastructure such as refurbishing the B-2 test stand for SLS core stage testing and replacing the A-leg and the B-leg of the high-pressure industrial water system, which supplies water to the large test stands.

RPT completed the SLS scale model acoustic testing at MSFC to enhance understanding of the effects of sound during launch of the SLS rocket. Personnel tested several rocket engine components, including those using developing technologies such as “metal printing” techniques. If proven successful, the “metal printing” technology could lead to significant improvements in rocket engine development and manufacturing processes.

At White Sands Test Facility, engineers conducted tests to support the Missile Defense Agency engine and thruster program, the Peacekeeper safing project, and hot fire test for the Minuteman life extension program. Additionally, through a reimbursable agreement, Boeing Corporation tested their orbital maneuvering and reaction control thrusters as part of NASA’s CCP. Early preparations and planning began for testing of the ESA/Orion service module and Boeing commercial crew service module. RPT also began rehabilitating their Large Altitude Simulation System to support testing in simulated high altitude space environment.

At Glenn Research Center Plum Brook Station (GRC-PBS), RPT performed tests in the B-2 facility on the Gamma-Ray Imager/Polarimeter for Solar Flares (GRIPS). This single test operated the critical thermal vacuum infrastructure continuously for 29.5 days. In addition to GRIPS testing, GRC-PBS continued critical facility maintenance and modernization projects further enabling the facilities hot fire capability.

## WORK IN PROGRESS IN FY 2016

At SSC, RPT will continue testing the RS-25 engine in support of the SLS program. Development testing will continue for commercial companies seeking to test their engine systems on a reimbursable basis.

# ROCKET PROPULSION TEST

These include testing USAF designed and developed Hydrocarbon Boost components for the RD-180 replacement project and Aerojet Rocketdyne hydrocarbon engine components. Planned refurbishment and repair activities, for critical enabling infrastructure include, completing replacement of the A and B-legs of the high-pressure industrial water system; continuing repair of SSC's liquid oxygen and liquid hydrogen barges; upgrading high-pressure gas facility; and replacing E-Complex data acquisition system. In addition to ongoing test programs, RPT will continue B-2 test stand refurbishment to prepare for SLS core stage testing.

The White Sands Test Facility team will conduct testing for the Missile Defense Agency, USAF, and U.S. Navy. Planning, design, and construction activities will take place to support future testing for the Boeing commercial crew service module (on a reimbursable basis) and the ESA Orion service module development. In addition to test and construction activities, White Sands Test Facility will continue refurbishment activities for the large altitude simulation system.

Marshall Space Flight Center will continue testing rocket engine technology improvements, including components constructed using select laser melting and other additive manufacturing processes that could lead to significant improvements in construction of these complex machines.

At GRC-PBS B-2 facility, engineers will perform an integrated system test to demonstrate the ability to perform small-scale rocket engine hot fire tests in a simulated space vacuum environment. RPT will also perform work to enable testing of electric propulsion thrusters to support exploration missions beyond low Earth orbit.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

Building on test results from previous years, RPT will provide valuable propulsion data to the SLS and Orion programs as they prepare for EM-1 and EM-2. These tests will provide critical data to validate baseline designs, increased confidence in technical performance while reducing risks, as well as assist in achieving launch readiness on schedule. This ongoing effort will allow the program to assess design changes that could affect performance and improve safety. Specifically, RPT personnel will continue hot fire testing the SLS RS-25 engine on SCC's A-1 test stand and begin SLS core stage testing on the newly refurbished B-2 test stand. The core stage uses four RS-25 engines to propel the SLS core stage upon launch.

RPT will complete WSTF facility preparations and construction activities and test the Orion ESA Service Module and Boeing CST-100 Service Module. RPT will complete refurbishing the large altitude simulation system at White Sands Test Facility, which supports future space environment testing for the Orion service module, Boeing commercial crew vehicle, Missile Defense Agency, and USAF test articles.

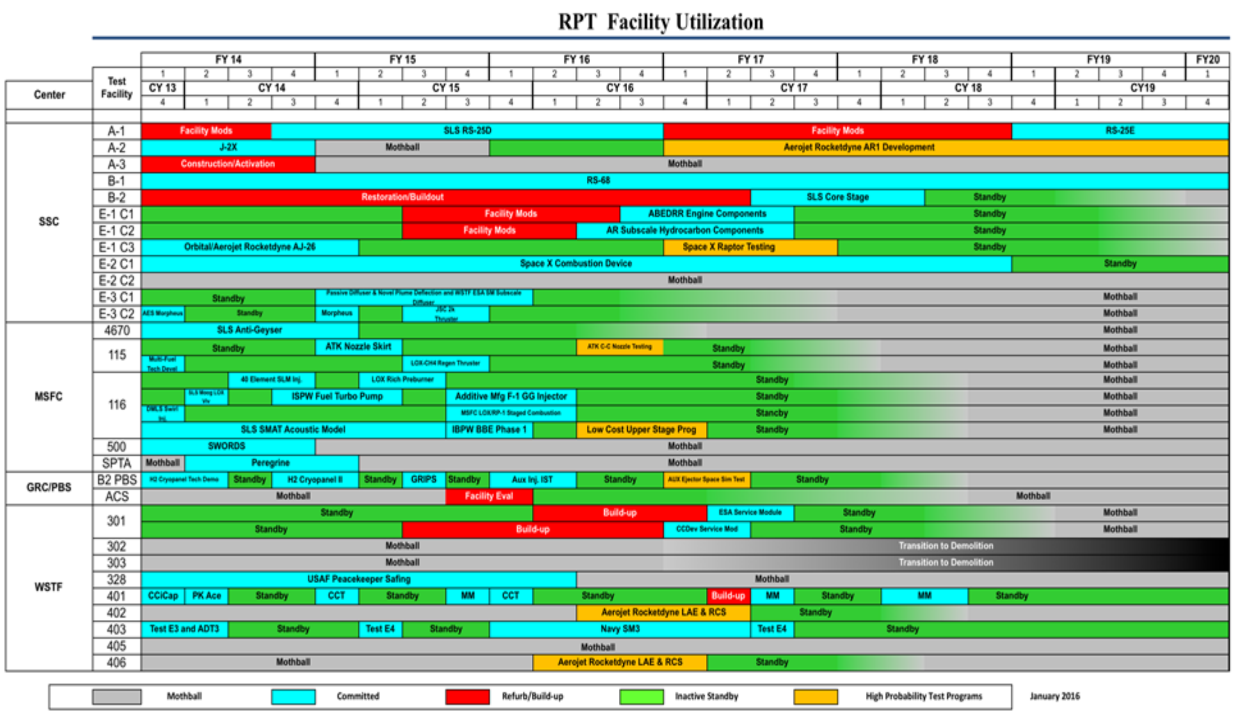
RPT will continue testing the Aerojet Rocketdyne RS-68 engine, as well as testing for USAF, SpaceX, and other commercial engine developers. RPT facilities and personnel will continue testing hazardous hypergolic fuels at White Sands Test Facility; these unique facilities are critical for testing future space vehicles in a simulated space environment and ambient conditions.

# Program Schedule

The following chart shows past, current, and planned test campaigns at SSC, MSFC, GRC and White Sands Test Facility rocket propulsion test facilities. The designations at the far left of the chart refer to the facility, the top of each chart shows time by quarter of fiscal and calendar year, and the key to the status of each facility is at the bottom.

Most test stands and facilities are solidly scheduled 18 months in advance. Defining scope of work, selecting test stands and fuel, and estimating labor and total cost to customers is a complex process that can take 18 to 36 months. RPT is working now with internal and external customer to design testing programs for FY 2017 and beyond.

***RPT Facility Utilization***



# ROCKET PROPULSION TEST

## Program Management & Commitments

| Program Element | Provider |
|---|---|
| RPT | Provider: RPT<br>Lead Center: N/A<br>Performing Center(s): SSC, JSC/White Sands Test Facility, GRC-PBS, MSFC, KSC, WFF<br>Cost Share Partner(s): Various other NASA programs, DoD, and commercial partners |

## Acquisition Strategy

No major acquisitions identified for FY 2017.

### MAJOR CONTRACTS/AWARDS

No major contracts or awards planned for FY 2017.

### INDEPENDENT REVIEWS

No reviews planned.

# EDUCATION

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Aerospace Research and Career Development | 58.0 | 58.0 | **33.0** | 33.0 | 33.0 | 33.0 | 33.0 |
| STEM Education and Accountability | 61.0 | -- | **67.1** | 69.1 | 71.1 | 73.2 | 75.3 |
| **Total Budget** | **119.0** | **115.0** | **100.1** | **102.1** | **104.1** | **106.2** | **108.3** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

# EDUCATION

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Aerospace Research and Career Development | 58.0 | 58.0 | **33.0** | 33.0 | 33.0 | 33.0 | 33.0 |
| STEM Education and Accountability | 61.0 | -- | **67.1** | 69.1 | 71.1 | 73.2 | 75.3 |
| **Total Budget** | **119.0** | **115.0** | **100.1** | **102.1** | **104.1** | **106.2** | **108.3** |
| Change from FY 2016 | | | **-14.9** | | | | |
| Percentage change from FY 2016 | | | **-13.0%** | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**Community college students operate the rover they designed, developed, and competed during a three-day workshop at Johnson Space Center (JSC) April 12-14, 2015. The workshop followed a five-week, online engineering design opportunity for 400 students from community colleges across the U.S. including 108 from minority serving institutions. Authentic STEM experiences in the first two years of college motivate students to pursue NASA-related STEM degrees and careers.**

Education is the single most important factor in determining not just whether our children can compete for the best jobs, but whether America can out-compete countries around the world. Building a robust Science, Technology, Engineering, and Mathematics (STEM) workforce for the 21st century and beyond requires the development of a stronger and more diverse pipeline for STEM, including women and individuals from underrepresented and underserved groups. 1

NASA's missions, including plans for the Journey to Mars, starts with a STEM-qualified and prepared workforce. The Administration places a high priority on STEM education at all levels, as reflected in the Five-Year Federal STEM Education Strategic Plan. NASA is committed to funding competitive, evidence-based programs in STEM education that will benefit aspiring learners, educators, and institutions.

NASA Education uses competitive processes to identify the most effective internal STEM education activities and assets across the Agency. NASA will make available its unique assets, such as the International Space Station (ISS), to STEM education programs, government-wide, on a reimbursable basis in order to enhance their effective reach to students and educators. NASA Education uses evidence-

1 https://www.whitehouse.gov/sites/default/files/docs/education_record.pdf

collection activities for performance measurement, analysis, evaluation, and reporting of NASA's activities.

NASA's education programs develop and deliver activities that support the growth of the Agency's and the Nation's STEM workforce, help develop STEM educators, engage and establish partnership with institutions, and inspire and educate the public. The Nation's economic competitiveness and the path to the American dream depends on providing all children with an education that will enable them to succeed in a global economy. The Administration continues to support ambitious national goals for preparing 100,000 new and effective STEM teachers, producing an additional one million more STEM college graduates over the next decade, and broadening participation in STEM fields for women and underrepresented minorities.

NASA Education's vision advances high quality STEM education using NASA's unique capabilities, assets, and expertise. This vision aligns to NASA's Strategic Objective 2.4: Advance the Nation's STEM education and workforce pipeline by working collaboratively with other agencies to engage students, teachers, and faculty in NASA's missions and unique assets in the Agency's 2014 Strategic Plan. NASA Education programs develop and execute strategic collaborations and partnerships with intergovernmental, academic, industrial, entrepreneurial, and international communities to achieve NASA's values, mission, and vision. Through its Education programs, NASA provides opportunities for educators, learners, and institutions that support the Five-Year Federal STEM Education Strategic Plan, prepared by the National Science and Technology Council's Committee on STEM Education (CoSTEM). NASA Education collaborates with other federal agencies in the key areas identified by CoSTEM, which include:

- improving STEM instruction and learning;
- increasing and sustaining youth and public engagement in STEM;
- enhancing the STEM experience of undergraduate students;
- providing STEM learning opportunities to groups historically underrepresented in STEM fields; and
- designing graduate education experiences for tomorrow's STEM workforce.

Through grants, cooperative agreements and Space Act agreements, NASA makes its people, resources, facilities, and discoveries available to key stakeholders and strategic partners, such as other federal agencies, educational organizations, and science museums. NASA Education uses competitive processes for allocating resources.

In FY 2017, NASA Education builds on the Administration's efforts to establish a stronger and more cohesive federal infrastructure for delivering STEM education and leveraging existing resources to expand the reach of the Agency's assets. NASA Education gives priority to two kinds of activities: 1) activities that use evidence to guide program design and implementation and 2) activities that build evidence about what works in STEM education, using appropriate metrics and improving the measurement of outcomes. NASA Education continues to implement rigorous evaluation. Impact evaluations require that:

- inferences about cause and effect are well-founded (internal validity);
- there is clarity about the populations, settings, or circumstance to which results can be generalized (external validity);

- measures accurately capture the intended information (measurement reliability and validity);
- samples are large enough for meaningful inferences; and
- evaluations are conducted with an appropriate level of independence by experts external to the program either inside or outside an agency.

Performance management and program evaluations should be aligned and complementary, where appropriate. Performance management tracks results on an ongoing basis to ensure efficiency.

NASA’s STEM education expertise, as well as the Agency’s unique missions and assets, make significant contributions to the Nation’s STEM education portfolio. The FY 2017 request for NASA Education is $100.0 million. Additionally, the Budget provides $25.0 million to NASA’s Science Mission Directorate (SMD) to support competitively selected cooperative agreements that will connect NASA-funded science to learners of all ages.

NASA continues to consolidate the education functions, assets, and efforts of the Mission Directorates, Offices, and Centers into the coordinated STEM Education and Accountability Projects (SEAP) under the auspices of NASA’s Office of Education (OE). A SEAP competition conducted in FY 2015 identified and prioritized NASA-unique assets and content for execution in FY 2016 by NASA Education and in support of other Federal agencies’ STEM efforts. FY 2017 activities capitalize on the excitement of NASA's missions of scientific inquiry and exploration through innovative solutions, approaches, and tools that inspire educator and learner interest and proficiency in STEM.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## ACHIEVEMENTS IN FY 2015

In a follow-on collaboration, NASA and the Department of Education entered into a second reimbursable Space Act Agreement increasing and sustaining youth and educator engagement in STEM. The partnership supported STEM objectives and activities within Department of Education's 21st Century Community Learning Center (21CCLC) program. NASA customized online STEM challenges and associated curriculum materials aligned to 21CCLC objectives and implemented them in 10 states: California, Colorado, Florida, New Jersey, Michigan, Montana, Oklahoma, Rhode Island, Virginia, and Wisconsin.

Between December 2014 and October 2015, NASA created ten education partnerships using NASA’s Space Act authority. This brings the total number of no-exchange-of-funds partnerships to more than 40 with diverse entities around the country. For example, the U.S. Department of Agriculture and NASA signed a Youth Engagement agreement focused on joint STEM education activities such as agriculture literacy, food science, and life science. To celebrate the signing of the STEM agreement along-side NASA’s Deputy Administrator Newman, local K-12 students planted seeds from romaine lettuce grown aboard the ISS in the U.S. Department of Agriculture (USDA)'s People's Garden in Washington, DC. To see the photo, go to: http://www.nasa.gov/image-feature/usda-and-nasa-plant-seeds-from-the-space-station

# EDUCATION

NASA executed a competition across the Mission Directorates, NASA Center's Offices of Education, and the Jet Propulsion Laboratory (JPL). The Priorities Competition for SEAP used criteria in an internal-to-NASA Request for Information (i-RFI). The FY 2015-2016 i-RFI for SEAP used these broad criteria: 1) Background; 2) Focus; and 3) Evidence of Effectiveness. The SEAP i-RFI ensured all submitters answered the same items and identified the priorities for selection. For preliminary results of the SEAP process, go to: http://www.nasa.gov/offices/education/about/seap-overview.html.

The American Association of Community Colleges recognized Dr. Toby Dittrich, Associate Director for the Oregon Space Grant consortium, for providing students seamless transfers to STEM four-year programs at Oregon colleges and universities. A Denver CBS-affiliated news station highlighted three Colorado Space Grant students for overcoming extreme personal challenges, including homelessness and gang affiliation, to participate in the RockOn! launch from NASA Wallops, VA. To view the success story, go to https://www.youtube.com/watch?t=12&v=BYjy-su59n.

The Agency developed and publicly released the NASA Education Implementation Plan 2015-2017 to guide the diverse elements, including external stakeholders, of the NASA education community toward better alignment with national priorities and Agency strategy, mission, goals and values. Go to the "About NASA Education" page on NASA.gov, to choose the desired format: a 4-page brochure; a 70-page plan or an electronically enhanced version of the 70-page plan that includes engaging video offerings.

## WORK IN PROGRESS IN FY 2016

The OE and SMD anticipate selecting 30 or more projects for implementation to support the Undergraduate Student Instrument Project (USIP) Student Research Flight Opportunity (SRFO) programmatic requirements, with an estimated total value of $6M for awards.

Experimental Program to Stimulate Competitive Research (EPSCoR), in collaboration with the ISS Office, will award five new ISS Flight Opportunities for the EPSCoR jurisdictions.

In November 2015, NASA Education launched the no-exchange-of-funds strategic partnerships for U.S. and international public and non-governmental entities competition to support mutually beneficial innovative education activities. In this new competition, NASA particularly sought efforts built around youth serving organizations, digital learning opportunities, STEM challenges and engagements or activities that reached underrepresented groups. For the full NASA Education partnerships criteria and competitive approach found in the NASA Announcement for High Impact/Broad Implementation STEM Education Partnerships [EDUCATION01SP16], go to http://go.nasa.gov/1RZwWCi.

NASA's OE coordinates with Headquarters' Offices of Communications, Diversity and Equal Opportunity, Chief Scientist, and Chief Technologist, and the Mission Directorates for the selection of proposals from the Competitive Program for Science Museums, Planetariums, and NASA Visitor Plus Other Opportunities (NASA Research Announcement (NRA) NNH15ZHA001N). In December 2015, about 70 youth-serving organizations, museums, planetariums, and NASA visitor centers in more than 25 states, Puerto Rico, and the Virgin Islands submitted proposals that are now under review with public announcement of selections expected in the last quarter of FY 2016 and/or first quarter FY 2017.

# EDUCATION

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA Education will focus on three main areas:

- continue to refine the technology infrastructure that provides support tools applicable to evidence-based program management and policy-making:
- conduct broad data collection and statistical analysis that reflect patterns, relationships, and anomalies in administrative and performance data sets: and
- perform internal and external program evaluation that assess and compare effectiveness of policy choices.

NASA Education will continue to provide a unified systematic and standardized approach to data collection and performance assessment. Objective and verifiable performance metrics, internal and external review processes, valid and reliable data collection instruments, and evaluation studies will assess progress and performance across the portfolio. To effectively monitor educational investments across the agency, NASA Education will collect and report performance data on all investments using the Office of Education Performance Measurement system. In addition to collecting data on activity outputs, such as counts of participants, NASA Education will develop and test new data collection instruments to assess short-term outcomes. NASA will actively participate in CoSTEM discussions on common metrics and instruments used across the federal government to monitor and assess the impact of federal STEM investments.

NASA Education will continue a robust, coordinated, and targeted evaluation process, which is essential for the Agency to measure and monitor program performance, make decisions for programmatic adjustments and changes, document program impact, identify best practices and lessons learned, help assess return on investment, provide inputs for policy, planning and budget decisions, and assure accountability to the American people.

# Programs

## AEROSPACE RESEARCH AND CAREER DEVELOPMENT

The Aerospace Research and Career Development (ARCD) program strengthens the research capabilities of the Nation's colleges and universities and provides opportunities that attract and prepare an increasing number of students for NASA-related careers. These institutions conduct research that contributes to NASA's Mission Directorate research needs and further the Nation's scientific and technology innovation agendas. These programs will continue to build, sustain, and effectively deploy the skilled, knowledgeable, diverse, and high-performing workforce needed to meet the current and emerging needs of NASA and the Nation.

The projects in the ARCD program are the National Space Grant College and Fellowship Program (Space Grant) and Experimental Program to Stimulate Competitive Research (EPSCoR).

## STEM EDUCATION AND ACCOUNTABILITY

The SEA program provides unique NASA assets, including its people, resources, and facilities to support the Nation's STEM education priorities. The projects within the SEA program are the Minority University Research and Education Project (MUREP) and SEAP.

The SEA program currently funds competitive grants, cooperative agreements, and professional development at NASA Centers for high school and college students, K-12 educators, and higher education faculty. The program enhances the education and research, academic, and technology capabilities of Historically Black Colleges and Universities (HBCU), Hispanic-Serving Institutions (HSI), Tribal Colleges and Universities (TCU), other Minority-Serving Institutions (MSIs), and the Nation's non-profit informal education institutions. It also provides opportunities for underrepresented and underserved learners to participate in research and education opportunities through internships, scholarships, and fellowships including opportunities for minority institutions to improve the quality of their faculty preparation programs, thereby improving the quality and diversity of future STEM leaders.

# AEROSPACE RESEARCH AND CAREER DEVELOPMENT

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| National Space Grant College and Fellowship Program (Space Grant) | 40.0 | 40.0 | **24.0** | 24.0 | 24.0 | 24.0 | 24.0 |
| Experimental Program to Stimulate Competitive Research (EPSCoR) | 18.0 | 18.0 | **9.0** | 9.0 | 9.0 | 9.0 | 9.0 |
| **Total Budget** | **58.0** | **58.0** | **33.0** | **33.0** | **33.0** | **33.0** | **33.0** |
| Change from FY 2016 | | | **-25.0** | | | | |
| Percentage change from FY 2016 | | | **-43.1%** | | | | |

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*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*


**The Montana Space Grant Consortium, established in 1991 as a component of NASA's National Space Grant College and Fellowship Program, supports various high altitude ballooning projects. Student Marty Seymour from Chief Dull Knife College prepares to launch a tethered balloon that proudly displays the Northern Cheyenne word for balloon along with the school's logo.**

ARCD supports national STEM efforts through Space Grant and EPSCoR.

The NASA Authorization Act of 1988 (P.L. 100-147) established Space Grant with a goal of enhancing the Nation's science enterprise by funding education, research, and public service projects through a national network of university-based Space Grant consortia. In 1992, the NASA Authorization Act, FY 1993 (P.L. 102-588) established EPSCoR to strengthen the research capability of jurisdictions that had not previously participated equitably in competitive aerospace research activities. The goal of the NASA EPSCoR is to provide seed funding that will enable jurisdictions to develop an academic research enterprise directed toward long-term, self-sustaining, nationally competitive capabilities in aerospace and aerospace-related research. This capability will, in turn, contribute to the jurisdiction's economic viability and expand the Nation's base for aerospace research and development.

These national projects enable NASA to advance STEM literacy more strategically by enhancing science and engineering education and research efforts in higher education, K-12, and informal education. In addition to fellowships, scholarships and internships with NASA Centers and STEM industry, ARCD promotes research and technology development opportunities for faculty and research teams that advance the Agency's scientific and technical priorities.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

# NATIONAL SPACE GRANT COLLEGE AND FELLOWSHIP PROGRAM (SPACE GRANT)

| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **40.0** | **40.0** | **24.0** | **24.0** | **24.0** | **24.0** | **24.0** |
| Change from FY 2016 | | | **-16.0** | | | | |
| Percentage change from FY 2016 | | | **-40.0%** | | | | |

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**South Dakota Space Grant student, Steven Hamman, participates in commencement activities with President Obama at the Lake Area Technical Institute. Mr. Hamman is a recipient of a $5,000 Space Grant award and is currently weighing two employment opportunities with Fortune 500 companies.**

Space Grant is a competitive grant opportunity that enables the active involvement of 52 consortia in 50 States, the District of Columbia, and the Commonwealth of Puerto Rico. Space Grant supports and enhances science and engineering education, and research efforts for educators and learners by leveraging the resource capabilities and technologies of over 900 affiliates from universities, colleges, industry, museums, science centers, and State and local agencies. Training grants with each consortium align their work with the Nation's STEM education priorities and the annual performance goals of the Agency.

Space Grant utilizes key NASA resources in order to provide students access to research and hands-on STEM experiences. Some of these activities include: high-altitude balloons, sounding rockets, aircraft, and space satellites. In order to maximize resources for these STEM investments, Space Grant leverages agency resources in STEM education through strategic collaborations with NASA Mission Directorates, Centers and subject matter experts.

In FY2015, Space Grant consortia received a new three-year training grant, titled Space Grant Opportunities in NASA STEM. All activities conducted by the 52 consortia are in alignment with agency goals, the OE lines of business, and the NSTC CoSTEM priority areas. Space Grant awards consist of scholarships, fellowships, or internships in support of higher education, research infrastructure, precollege, and informal education. Space Grant consortia also supported flight project activities led by student teams. Some of those flight activities included, but are not limited to:

- RockOn! Workshop

# NATIONAL SPACE GRANT COLLEGE AND FELLOWSHIP PROGRAM (SPACE GRANT)

| Formulation | Development | Operations |
|---|---|---|

- RockSat-C
- RockSat-X
- DemoSat
- High Altitude Student Platform (HASP)

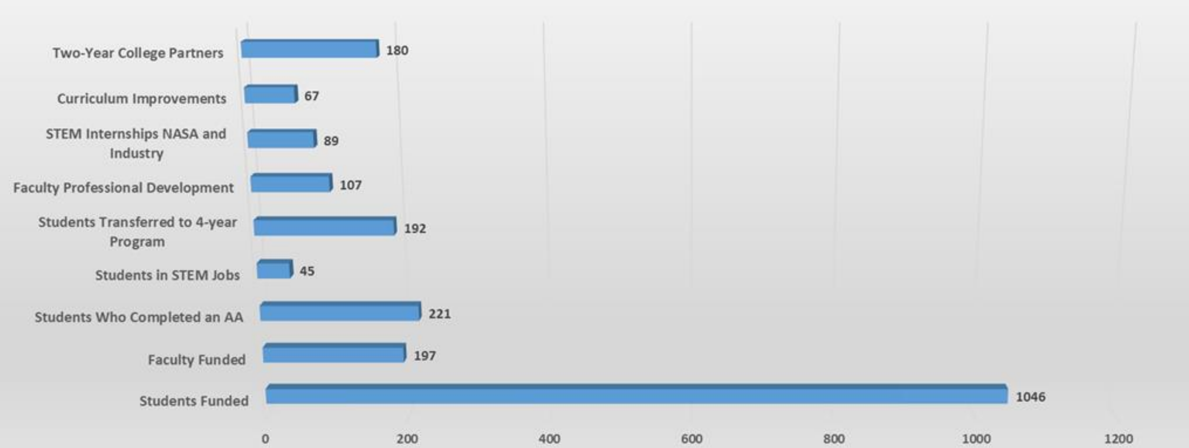
## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## ACHIEVEMENTS IN FY 2015

NASA Space Grant awarded 35 Community Colleges and Technical Schools (CC/TS) partnerships grants to increase students and faculty engagement in STEM across the U.S. The selected awards outlined innovative ways to attract and retain more STEM students from CC/TS through competitive STEM scholarships, distance learning STEM courses for students and faculty, and internship opportunities at NASA Centers. Figure 1.1 shows a total of 1,046 CC/TS students received funding and 221 students received their Associates of Arts (AA) degree.

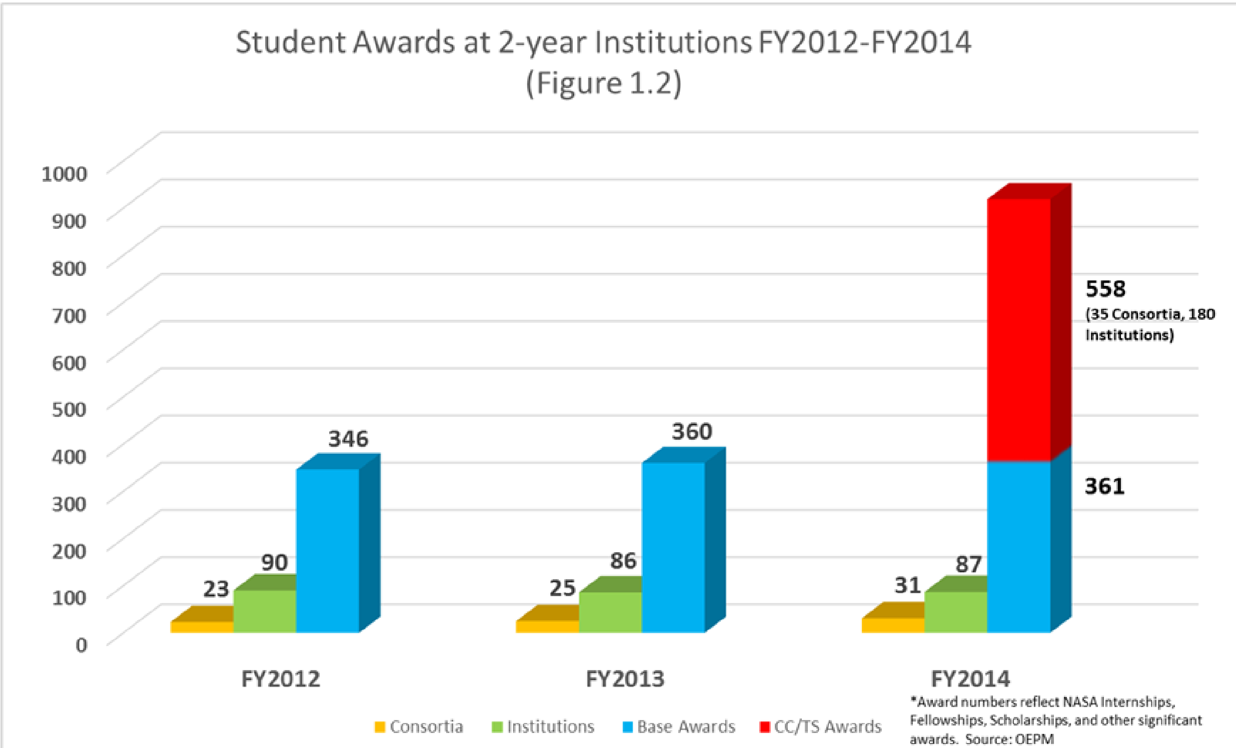
Space Grant Two-Year College Engagement Awards 2015
(Source: CC/TS Year-1 Annual Performance Reports)
Figure 1.1




The following Figure 1.2 shows the data trend of CC/TS students who received NASA Internship, Fellowship, Scholarship, and other significant awards through the Space Grant program during 2012-2014. Significant Awards = ≥ $5,000 or ≥ 160 or contact hours.

# NATIONAL SPACE GRANT COLLEGE AND FELLOWSHIP PROGRAM (SPACE GRANT)

| Formulation | Development | Operations |
| --- | --- | --- |




- As noted in Figure 1.2 above, the total involvement of NASA Internship, Fellowship, Scholarship, and other significantly awarded CC/TS students in 2012 was about 350 students and 90 CC/TS institutions in 23 out of the 52 Space Grant Consortia.
- In 2014, the number of NASA Internship, Fellowship, Scholarship, and other significantly awarded CC/TS students increased to 361 students with participation from 87 CC/TS institutions in 31 Space Grant Consortia.
- Of the 1,046 funded students who participated in the CC/TS award, 558 of these were students who received NASA Internships, Fellowships, Scholarships greater than or equal to $5,000 or at least 160 contact hours, resulting in a 61 percent increase over a two-year period.
- Another indicator of the CC/TS program's impact is that 235 students have moved on to four-year institutions and STEM employment. Since this is only the first year of the two-year award program, this number will increase next year.
- In an effort to increase the sustainability of these programs, initiatives include developing articulation agreements with four-year institutions, curricular development, or improvement, as well as cultivating opportunities for additional industry internships. For more information on the 35 community colleges and technical schools awards, please visit http://go.nasa.gov/1svsrWD.
- The American Association of Community Colleges recognized Dr. Toby Dittrich, Associate Director for the Oregon Space Grant consortium, for providing students seamless transfers to STEM four-year programs at Oregon colleges and universities.

# NATIONAL SPACE GRANT COLLEGE AND FELLOWSHIP PROGRAM (SPACE GRANT)

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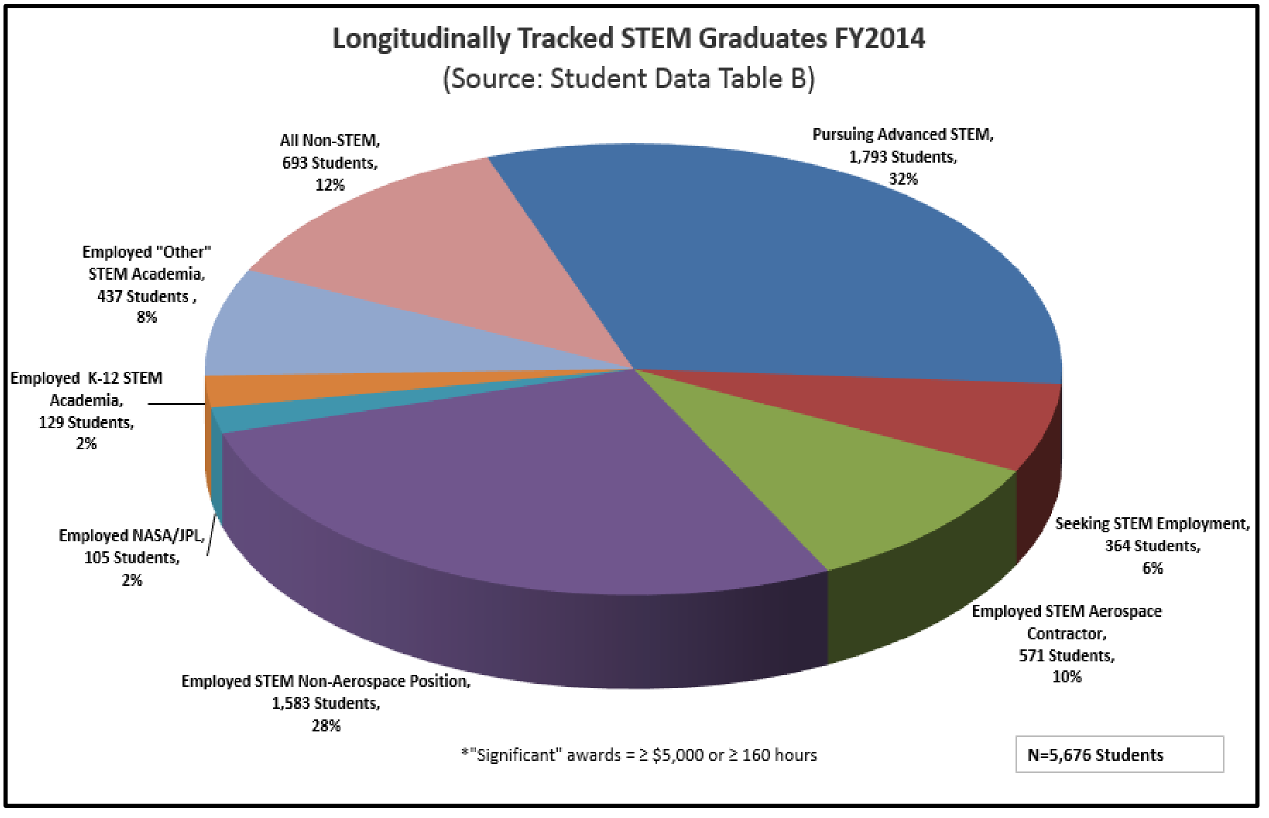
- A Denver CBS affiliated news station highlighted three Colorado Space Grant students for overcoming extreme personal challenges, such as homelessness and gang affiliation to participate in the RockOn! launch from NASA Wallops, VA. To view this success story, please visit https://www.youtube.com/watch?t=12&v=BYjy-su59n.
- In the final year of the 2010-2014 Space Grant Training Grant, more than 4,500 undergraduate and graduate students through scholarships, fellowships, internships and authentic hands-on research and engineering challenges received awards. The program achieved 26 percent participation among underrepresented students and 40 percent participation among female students in Space Grant activities.
- Space Grant targeted elementary and secondary students through NASA informal education activities, web-based activities, and other instructional and enrichment activities; reaching more than 152,000 precollege students and more than more than 17,900 educators.




*FY 2014 data is the most current data. FY 2015 Data is not available until June 2016.*

# NATIONAL SPACE GRANT COLLEGE AND FELLOWSHIP PROGRAM (SPACE GRANT)

| Formulation | Development | Operations |
|---|---|---|

## WORK IN PROGRESS IN FY 2016

Space Grant consortia are currently implementing activities outlined in their three-year strategic plans. In addition to those activities, the Space Grant program office at NASA Headquarters is planning to release a solicitation that augments the three-year awards. The consortia also continues to implement their community college/technical school awards during this fiscal year.

Finally, the consortia are currently developing proposals for the USIP SFRO, a partnership between Space Grant and the NASA SMD. The USIP SRFO proposals are specifically for an undergraduate student team to design, develop, and fly a science and/or technology investigation relevant to NASA strategic goals and objectives on a sounding rocket, balloon, aircraft, suborbital reusable launch vehicle (sRLV), other commercial suborbital vehicle, or CubeSat launched as a secondary payload on an orbital vehicle. The two goals of the USIP SRFO are:

- To provide a hands-on flight project experience to enhance the science, technical, leadership, and project skills for the selected undergraduate student team.
- To fly a science and/or technology investigation relevant to NASA strategic goals and objectives on a suborbital-class platform.
- The Space Grant program office at NASA Headquarters continues to prepare for an independent external evaluation of the national program, incorporating the results from the external evaluation into strategic planning for the Space Grant program.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

The budget supports base awards for the 52 consortia to do the following:

- Provide hands-on experiences for U.S. graduate and undergraduate students to prepare them for the future workforce and/or academic careers;
- Conduct programs and projects that align with the NASA Education priorities, CoSTEM, missions, and State-specific needs to build upon the education pipeline in higher education, research infrastructure, precollege and informal education;
- Promote a strong STEM education base from elementary through secondary levels while preparing teachers in these grade levels to become more effective at improving student academic outcomes;
- Build upon and maintain the existing national network of universities with interests and capabilities in aeronautics, space, and related fields; and
- Leverage the opportunities emerging from the NASA Education strategy to develop high-impact, nationwide partnerships.

# NATIONAL SPACE GRANT COLLEGE AND FELLOWSHIP PROGRAM (SPACE GRANT)

| Formulation | Development | Operations |
|---|---|---|

## Project Schedule

| Date | Significant Event |
|---|---|
| Q1 FY 2017 | Release of Solicitations |
| Q2 FY 2017 | Proposals Due and Review Process |
| Q3 FY 2017 | Selection and Awards |
| Q4 FY 2017 | Prior Fiscal Years' Performance Data Due |

## Project Management & Commitments

The Space Grant Project Manager at NASA Headquarters provides management responsibility for day-to-day Space Grant operations. Civil servants at NASA centers actively engage with regional space grant consortia, providing direction, oversight, and integration with Center and Mission Directorate activities.

## Acquisition Strategy

NASA solicits through full and open competition for proposals accepted from Space Grant 52 consortia in 50 States, District of Columbia, and the Commonwealth of Puerto Rico. Each consortium program or project must align with the Administration's and NASA's Strategic Plans for education. All award selections undergo rigorous peer reviews by internal/external panels that evaluate technical merit, assess content, feasibility, and alignment to Agency education, research, and technology goals. Awards are typically multi-year.

### MAJOR CONTRACTS/AWARDS

None.

### INDEPENDENT REVIEWS

The OE Evaluation Manager and the Space Grant Program office are engaged in community consultation and planning to support the next evaluation. Paragon TEC, the technical assistance provider was tasked with the following:

- Document the current Space Grant program model, including inputs, strategies/activities, outputs, and short-, intermediate-, and long-term outcomes in consultation with the Space Grant community

# National Space Grant College and Fellowship Program (Space Grant)

| Formulation | Development | Operations |
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- Conduct an assessment of performance data, reporting and program documentation held by Space Grant consortia and the NASA OE to ensure that appropriate, valid and reliable data are collected to document program activities, outputs, and outcomes; and
- Prepare a design and plan for an external evaluation study and make formal recommendations to improve NASA's performance monitoring.

Key technical findings and recommendations to NASA included the following:

- Prioritize data collection required for agency-level performance reporting because the data quality assessment found that a limited number of data elements were comparable across Space Grant consortia to capture program activity, outputs and outcomes;
- Consider consolidating tracking of students at NASA and use a professional service to conduct employment and enrollment verification; and
- Publish a program-level annual performance report in order to inform consortia about the status of the program and data quality.

For additional information, please visit:
http://www.nasa.gov/sites/default/files/atoms/files/spacegrant_final_oct-2015.pdf.

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Independent/External | TBD | Apr 2016 | To provide an independent review by an external organization to assess the accomplishments and strategy of the Space Grant Program | A 6-month preliminary interim report expected by September 2016. The report will also provide recommendations for the new 5-year Space Grant solicitation, which will be released during Quarter 1 of FY 2017 | Apr 2017 |

# Experimental Program to Stimulate Competitive Research (EPSCoR)

| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **18.0** | **18.0** | **9.0** | **9.0** | **9.0** | **9.0** | **9.0** |
| Change from FY 2016 | | | **-9.0** | | | | |
| Percentage change from FY 2016 | | | **-50.0%** | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**NASA EPSCoR project researcher, Dr. Jordi Cristóbal training undergraduate student Patrick Graham in setting up field equipment used to collect calibration and validation (CalVal) data. Airborne and satellite missions, as well as local and regional scale surface energy balance models that use input data from NASA satellite missions require such CalVal data for quality control and for quantitative studies.**

The EPSCoR provides cooperative agreement opportunities designed to establish partnerships between government, higher education, and industry in an effort to build stronger research and development capabilities in the 27 jurisdictions (states or regions). The program strives to improve a jurisdiction's research infrastructure to a level such that its research and development programs contribute to its economic development. EPSCoR funds research in jurisdictions with modest research infrastructure to help establish a long-term, self-sustaining, and nationally competitive program so that they become more competitive in attracting non-EPSCoR funding.

National Science Foundation (NSF) uses the latest eligibility tables to determine overall jurisdiction eligibility for NASA EPSCoR. The NSF 2015 eligibility table is available at: http://www.nsf.gov/od/iia/programs/epscor/Eligibility_Tables/FY2015_Eligibility.pdf.

EPSCoR supports competitively funded awards and provides research and technology development opportunities for faculty and research teams. NASA actively seeks to integrate the research conducted by EPSCoR jurisdictions with the scientific and technical priorities pursued by the Agency.

## Explanation of Major Changes in FY 2017

None

# EXPERIMENTAL PROGRAM TO STIMULATE COMPETITIVE RESEARCH (EPSCoR)

| Formulation | Development | Operations |
|---|---|---|

## ACHIEVEMENTS IN FY 2015

NASA EPSCoR funded academic research has provided benefits in the following four areas:

- Increased competitive research capacity within targeted jurisdictions. All NASA 2014-2015 EPSCoR status reports are in an on-line document titled Stimuli at http://go.nasa.gov/1YakIhf. This document highlights EPSCoR-funded research accomplishments around the country.
- The University of North Dakota (UND) developed a Multi-Purpose Research Station in North Dakota designed to expand NASA space exploration-relevant research and help our next generation of explorers reach new worlds beyond Earth. The UND research resulted in:
    - 39 published papers
    - 74 talks and presentations
    - 63 new grants valued at $5,452,405 from agencies such as the Department of Energy, the Office of Naval Research, the NSF, the USDA, and the U.S. Environmental Protection Agency.
- Generation of advanced technology as evidenced by the awarding of patents.
    - Patent US 08695156 B2 developed by the University of Vermont for an aero-acoustic duster invention that provides for particle removal from surfaces using less energy than competing vacuum-cleaner devices. The complete details of the patent are at http://www.patentorg.com/aeroacoustic-duster-details-187386.
    - Researchers from University of Puerto Rico patented an approach to diamond induction by employing iron nanoparticles to induce the synthesis of diamond on molybdenum, silicon, and quartz substrates. (Patent #: US 8,784,766 B1–Issue Date – July 22, 2014). This is a spin-off patent to several earlier patents. The complete details of the patent are at https://www.google.com/patents/US8784766?dq=US8784766B1&hl=en&sa=X&ved=0ahUKEwj-0d_n5rvKAhWEJR4KHZOCBRoQ6AEIHDAA.
    - Researchers from the South Dakota School of Mines and Technology (SDSMT) patented "Alignment of carbon nanotubes comprising magnetically sensitive metal oxides in nanofluids," Patent Number: US 8,652,386 B2, issued: Feb 18, 2014. The complete details of the patent are at http://www.google.com/patents/US8652386.
- Demonstrated research productivity among EPSCoR funded faculty and postdoc researchers.
    - A total of 636 faculty and postdoc researchers participated in a total of 536 talks/presentations at professional meetings. Additionally, 307 peer reviewed publications were accepted or published, and 169 other publications were accepted or published.

## WORK IN PROGRESS IN FY 2016

EPSCoR will make new research awards based on availability of funding. Each funded proposal will establish research activities with the potential to make significant contributions to NASA's strategic research and technology development priorities and contribute to the overall research infrastructure, science and technology capabilities, higher education, and economic development within the EPSCoR jurisdiction.

# EXPERIMENTAL PROGRAM TO STIMULATE COMPETITIVE RESEARCH (EPSCoR)

| Formulation | Development | Operations |
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EPSCoR, in cooperation with the ISS Program Office, will award five new ISS Flight Opportunities for the EPSCoR jurisdictions. Additionally, EPSCoR uses its collaboration with the nine NASA centers and JPL to provide workshops aimed at increasing the jurisdiction's knowledge of NASA's unique and innovative capabilities, resources, and facilities.

### KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA EPSCoR will issue a competitive call for extramural Research Infrastructure Development (RID) and ISS Flight Opportunity proposals, and support Space Technology Mission Directorate/EPSCoR workshops. NASA EPSCoR research priorities are defined by the Mission Directorates (Aeronautics Research, Human Exploration & Operations, SMD, and Space Technology), and NASA's ten Centers. Each funded NASA EPSCoR proposal establishes research activities that will make significant contributions to the strategic research and technology development priorities of one or more of the Mission Directorates, and contribute to the overall research infrastructure, science and technology capabilities, higher education, and economic development of the jurisdiction. For example, one of the Aeronautics Research Mission Directorate research priority is green aviation: enabling fuel-efficient flight planning, reductions in aircraft fuel consumption, emissions, and noise. For additional information on NASA research NSPIRES solicitations, please visit http://nspires.nasaprs.com (select "Solicitations" and then "Open Solicitations"). Appendix A provides a summary of Research priorities for each of the Mission Directorates and Centers.

## Project Schedule

| Date | Significant Event |
|---|---|
| Q1 FY 2017 | Release of Solicitations (Research and Research Infrastructure Development Opportunities) |
| Q2 FY 2017 | Proposals Due and Review Process (Research and Research Infrastructure Development Opportunities) |
| Q3 & Q4 FY 2017 | Selection and Awards (Research and Research Infrastructure Development Opportunities) |

## Project Management & Commitments

The program manager for NASA EPSCoR resides at NASA Headquarters and is responsible for overall administrative duties of this national project. The project manager is located at Kennedy Space Center (KSC) and provides management responsibility for day-to-day operations. Contractor staff and representatives from each NASA Mission Directorate work closely with EPSCoR project management to ensure that current and future research requirements are in EPSCoR solicitations. The Mission Directorate

# EXPERIMENTAL PROGRAM TO STIMULATE COMPETITIVE RESEARCH (EPSCoR)

| Formulation | Development | Operations |
|---|---|---|

representatives serve as the proposal selection committee, further ensuring that the selected work contributes to NASA priorities. Technical monitors at the NASA centers and Headquarters monitor and assess the progress of each award. They provide scientific guidance and technical advice as required throughout the year regarding the overall progress of the proposed effort, and review all progress reports. Additional involvement may occur, depending upon the nature of the collaboration already established or desired. This includes integrating the EPSCoR research into ongoing activities or research efforts, and increasing the principal investigator's and his or her team's awareness of other related or relevant research in NASA. NASA is a member of the Federal EPSCoR Interagency Coordinating Committee (EICC), chaired by the NSF. The committee works to improve the leveraging of Federal EPSCoR investments. NASA EPSCoR continues to develop strategies to adhere to the guidance within the America COMPETES Act.

## Acquisition Strategy

NASA solicits and awards EPSCoR grants through a competition among institutions from designated EPSCoR States. Each jurisdiction's proposal must align with the Administration's and NASA's strategic plans for education. All award selections undergo rigorous peer reviews by internal/external panels that evaluate technical merit, assess content, feasibility, and alignment to Agency education, research, and technology goals. Awards are typically multi-year.

### MAJOR CONTRACTS/AWARDS

None.

# EXPERIMENTAL PROGRAM TO STIMULATE COMPETITIVE RESEARCH (EPSCoR)

| Formulation | Development | Operations |
|---|---|---|

## INDEPENDENT REVIEWS

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
|---|---|---|---|---|---|
| Independ-ent | National Academy of Sciences | Nov 2013 | Cross-agency evaluation of EPSCoR and other Federal EPSCoR-like programs and accomplishments per H.R. 5116 America COMPETES Reauthorization of 2010. | NASA incorporated the findings of the November 2013 report of the National Academy of Sciences on the EPSCoR program into its FY 2017 budget request. NASA continues to participate in the Federal EICC, meetings in FY 2017. | N/A |

# STEM EDUCATION AND ACCOUNTABILITY

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Minority University Research Education Project | 32.0 | -- | **30.0** | 30.0 | 30.0 | 30.0 | 30.0 |
| STEM Education and Accountability Projects | 29.0 | -- | **37.1** | 39.1 | 41.1 | 43.2 | 45.3 |
| **Total Budget** | **61.0** | -- | **67.1** | **69.1** | **71.1** | **73.2** | **75.3** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**SEAP funded students work to develop models using 3D printing to demonstrate the effects of air currents on a unique wing design.**

The SEA program provides unique NASA assets, including people, resources, and facilities to support the Nation's STEM education priorities. Through the competitive award of federal domestic assistance funds and collaboration with other Federal agencies such as the Department of Education, the NSF, and Smithsonian Institution, the program provides students and educators with access to NASA assets and content. It connects NASA's partners, including higher education institutions, minority-serving institutions, community colleges, NASA visitor centers, museums, planetariums, and other youth serving organizations to the exciting and compelling content emanating from NASA's scientific discoveries, aeronautics research, and exploration endeavors.

NASA provides multi-year grants and cooperative agreements to the Nation's HBCUs, HSIs, TCUs, and other MSIs through MUREP. MUREP awardees provide internships, scholarships, fellowships, mentoring, and tutoring for underserved and underrepresented learners in K-12, informal, and higher education settings, (including community colleges, particularly those serving a high proportion of minority and underserved students, persons with disabilities, and women).

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

# MINORITY UNIVERSITY RESEARCH EDUCATION PROJECT

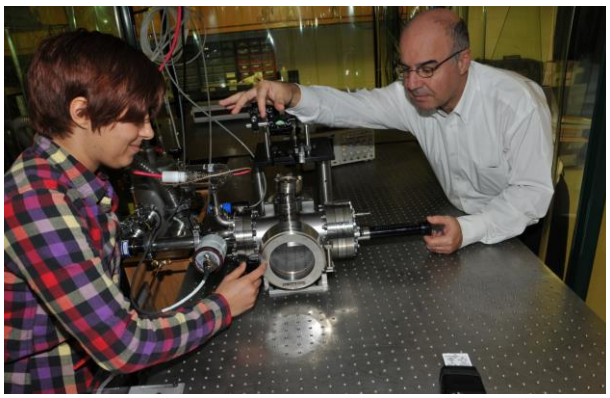
| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **32.0** | **--** | **30.0** | **30.0** | **30.0** | **30.0** | **30.0** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**Ms. Alissa Mezzacappa, NASA Minority University Research and Education Opportunity (MIRO) Scholar and PhD Candidate in Applied Optics and Dr. Noureddine Melikechi, NASA MIRO Principal Investigator at Delaware State University aligning optical set-up and preparing to take measurements of samples. This PhD program is the first of its kind among HBCUs.**

NASA provides financial assistance (grants and cooperative agreements) to the Nation's HBCUs, HSIs, Asian American and Native American Pacific Islander-Serving Institutions (AANAPISI), TCUs, American Indian and Alaskan Native Serving Institutions (AIANSI), Predominantly Black Institutions (PBI) and eligible community colleges. The Administration recognizes the valuable role that these institutions play in educating our citizens, as reflected in the five MSIs focused Executive Orders signed by the President. These institutions recruit and retain underrepresented and underserved students, including women and girls, and persons with disabilities into STEM fields. Participation in NASA projects and research has the potential to stimulate increasing numbers of learners to continue and complete their studies at all education levels and encourages students to earn advanced degrees in STEM fields that are critical to NASA and the Nation.

NASA's MUREP investments enhance the research, academic, and technology capabilities of MSIs through multi-year awards. Awards assist faculty and students in research and provide authentic STEM engagement related to NASA missions. These competitive awards provide NASA specific knowledge and skills to historically underrepresented and underserved learners in STEM. MUREP investments also assist NASA in meeting the goal of a diverse workforce through student participation in internships, scholarships, and fellowships at NASA Centers and JPL. MUREP provides financial assistance via competitive awards to MSIs and eligible community colleges, consistent with the goals of the five MSI focused Executive Orders. These institutions recruit and retain underrepresented and underserved students, including women and girls, and person with disabilities, into STEM fields.

# MINORITY UNIVERSITY RESEARCH EDUCATION PROJECT

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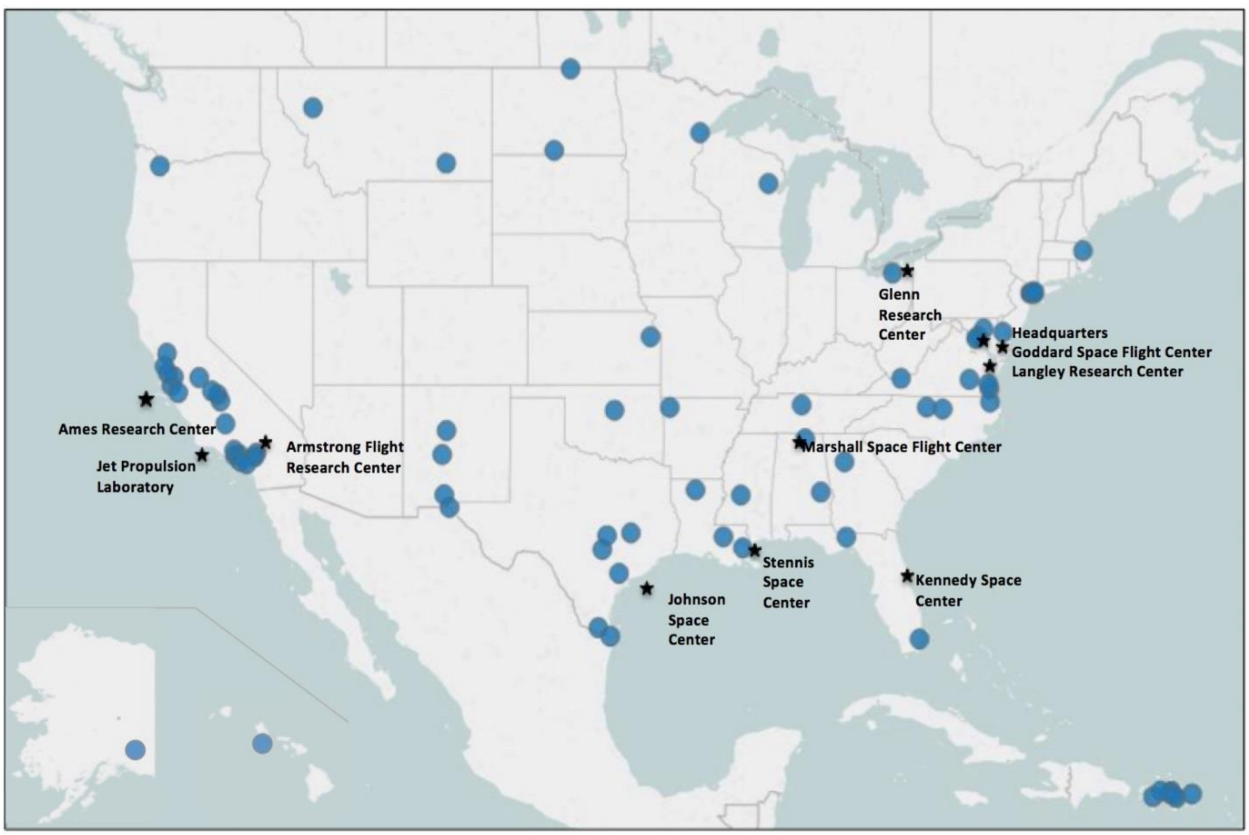
## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## ACHIEVEMENTS IN FY 2015

MUREP provided oversight to 111 active MSI awards across the United States. MUREP informs faculty and students about NASA's competitive research and education opportunities with the focus of increasing retention rates and degree completion at each educational level at MSIs in NASA-related fields. In addition, these awards also provide opportunities for MSIs to improve educators' professional development and thereby better serve groups historically underrepresented and underserved in STEM.

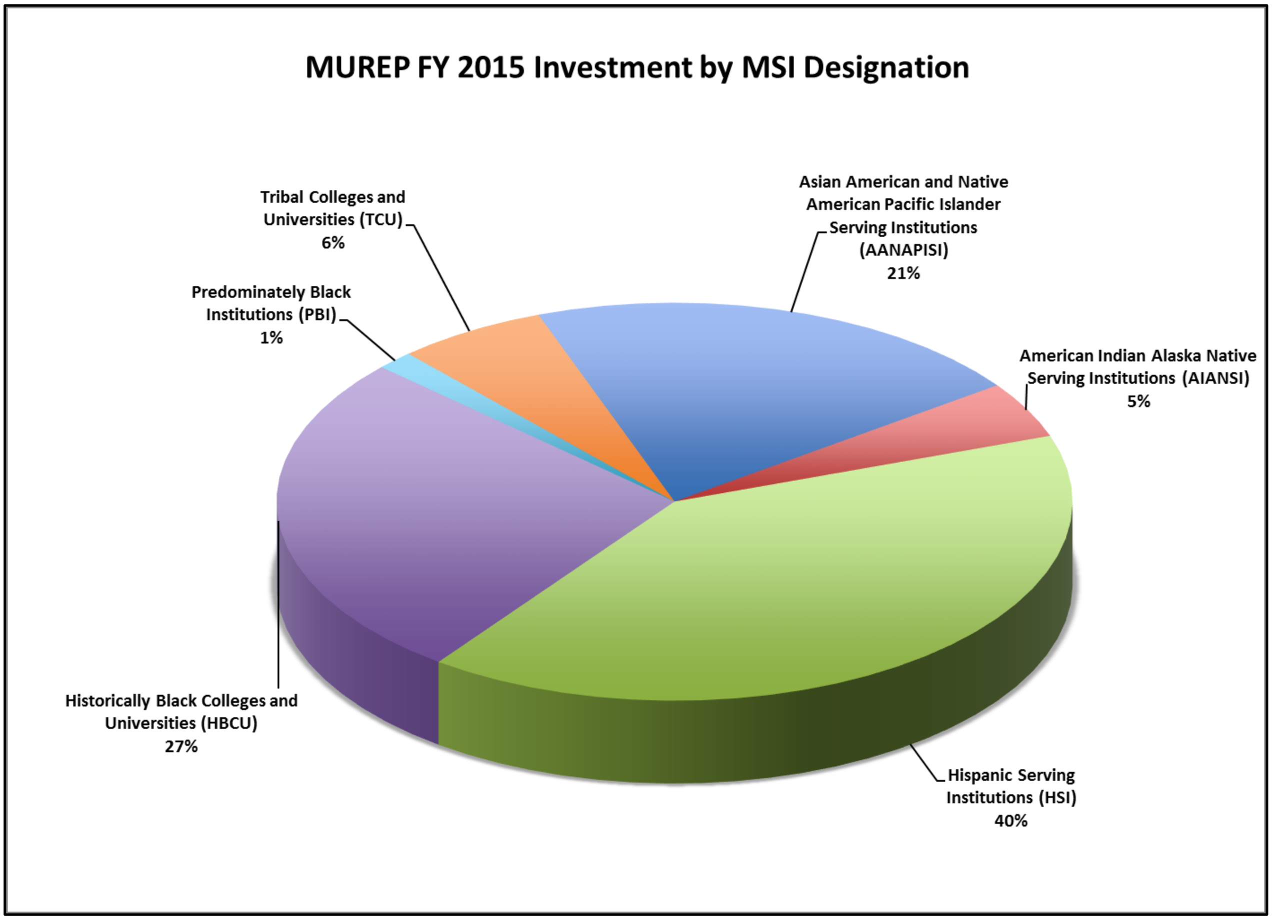
**FY2015 MUREP Awards by Location**




****Note: Some dots may represent more than one Institution for Institutions located in the same city.**

# MINORITY UNIVERSITY RESEARCH EDUCATION PROJECT

| Formulation | Development | Operations |
|---|---|---|




****Note: Some Institutions have dual MSI designations.**

In FY 2015, MUREP received an additional $2M that was distributed through a competitive solicitation entitled MUREP Other Opportunities (MOO). MOO selected four universities to receive awards, which provide up to a total of $500,000 to each school for a three-year performance period. The solicitation challenged schools to propose innovative ways to create and implement STEM activities, with a goal of increasing the number of historically underserved students studying STEM fields relevant to NASA's diverse exploration mission. For more information on this selection, please review the NASA Press Release. (https://www.nasa.gov/press-release/nasa-awards-grants-to-broaden-stem-education-for-underserved-students)

MUREP's Earth Systems, Technology, and Energy Education for MUREP (ESTEEM) is a competitive project designed to increase the climate literacy and level of engagement of the United States public. The goal is to create a diverse, highly skilled, and motivated future workforce in climate-related sciences. Awardees from 33 states across the nation and Washington, DC have participated in this project activity, with a key priority to collaborate with MSIs. ESTEEM operates in a collaborative partnership with NASA's SMD, NSF, and National Oceanic and Atmospheric Administration (NOAA). A few FY 2015 achievements of ESTEEM include:

# MINORITY UNIVERSITY RESEARCH EDUCATION PROJECT

| Formulation | Development | Operations |
|---|---|---|

- ESTEEM served 730 undergraduate and graduate students, 617 elementary and secondary students, 165 higher education faculty, 52 teachers, and 190 administrators and members of the general public directly participated in activities developed by the awardees. Examples of ESTEEM's engagement:
  - Ask Useful Science (Ask US) Google+ Hangout series designed to expand learning for Educators on a virtual platform and to extend the reach of NASA's unique content to audiences throughout the nation reached over 1400 educators. For additional information, please visit: http://esteem.larc.nasa.gov/ask-us/.
  - ESTEEM continues the development and implementation of the Tri-Agency Climate Education (TrACE) catalog, a comprehensive online catalog of educational resources developed by members of the tri-agency community (NASA, NSF, and NOAA). TrACE is an interactive, searchable web interface that contains a wide spectrum of project information to help users find relevant earth system science and climate change education resources. Currently, the TrACE catalog contains over 200 climate education resources, submitted by 86 tri-agency funded projects. For additional information, please visit: https://trace.larc.nasa.gov.
- The MUREP Institutional Research Opportunity (MIRO) aims to promote literacy in STEM at MSIs and to enhance the sustainable capabilities of institutions to perform research and education aligned to NASA's mission. In 2015, the MIRO Optical Science Center for Applied Research (OSCAR) at Delaware State University awarded its first PhD. in Applied Optics to Dr. Leon Taleh. Delaware State is one of only about a dozen institutions nationwide to offer a PhD. in Optics and the only HBCU.
- Ms. Alissa Mezzacappa, the second PhD. in Optics funded by the MIRO award at Delaware State, graduated December 2015. Alissa is a member of the MARS Science Laboratory, ChemCam Instrument Development & Science Team that received the NASA Group Achievement Award in 2014.

## WORK IN PROGRESS IN FY 2016

MUREP continues to fund efforts to help prepare historically underrepresented and underserved students in NASA specific STEM disciplines and careers. MUREP funding will be used to maintain active agreements and awards for HBCUs, HSIs, TCUs, AANAPISIs, AIANSIs, PBIs other MSIs, and non-profit organizations that contribute to the Agency's workforce diversity and MUREP's goals. For NASA's full report of accomplishments in MUREP, go to http://www.nasa.gov/offices/education/performance/index.html.

MUREP provides competitive funding opportunities to MSIs through an omnibus solicitation called Educational Opportunities in NASA STEM (EONS). EONS can be located at the NASA Solicitation and Proposal Integrated Review and Evaluation System website. MUREP will release EONS 2016 in preparation for FY 2017 awards. For more information, go to http://nspires.nasaprs.com.

# MINORITY UNIVERSITY RESEARCH EDUCATION PROJECT

| Formulation | Development | Operations |
|---|---|---|

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

According to the Science and Engineering Indicators 2014, the proportion of students planning to major in science and engineering are lower for women in every racial and ethnic underrepresented group in STEM. The White House Executive Order 13506 echoes the lack of women and girls in STEM fields including women of color and those with disabilities. In FY 2017, MUREP will support efforts to increase retention and graduation rates for women of color in STEM fields. Likewise, in February 2014, the administration launched the “My Brother’s Keeper Initiative” to build ladders of opportunity for boys and young men of color. MUREP will leverage strategic efforts to reach boys and young men of color with opportunities in STEM. All MUREP activities map to the annual performance indicators. MUREP investments assist NASA in meeting the goal of a diverse future workforce through student participation in NASA-related internships, fellowships, and scholarships at NASA Centers. MUREP contributes to the diversity of activities in NASA Education. NASA targets recruitment and retention of underrepresented and underserved students, including women and girls, and persons with disabilities, into the STEM fields in all education programs.

MUREP investments enhance the research, academic, and technology capabilities of MSIs through multi-year awards. MUREP funding will be used to maintain active agreements and awards for HBCUs, HSIs, TCUs, AANAPISIs, AIANSIs, PBIs other MSIs, and non-profit organizations that contribute to the Agency’s workforce diversity and MUREP's goals.

## Project Schedule

MUREP implements a consolidated investment through the NRA EONS. NASA plans to release a new EONS opportunity no later than the last quarter of FY 2017 with a rolling schedule of opportunities through FY 2018.

| Date | Significant Event |
|---|---|
| Q1 FY 2017 | Release of Solicitations (EONS Appendix Opportunities) |
| Q2 FY 2017 | Proposals Due and Review Process (EONS Appendix Opportunities) |
| Q3 & Q4 FY 2017 | Selection and Awards (EONS Appendix Opportunities) |

## Project Management & Commitments

The MUREP project manager is located at NASA Headquarters and provides management and oversight for overall activity operations. NASA centers manage significant investments in project activity elements. The current MUREP elements are as follows:

# MINORITY UNIVERSITY RESEARCH EDUCATION PROJECT

| Formulation | Development | Operations |
|---|---|---|

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| MIRO | MIRO is designed to establish significant, multi-disciplinary, scientific, engineering, and/or commercial research centers at the host MSI, that contribute substantially to the programs of one or more of the NASA Mission Directorates as described in the 2014 NASA Strategic Plan. | Provider: All NASA Centers<br>Lead Center: Armstrong Flight Research Center<br>Performing Center(s): All NASA Centers<br>Cost Share Partner(s): N/A | |
| MUREP Community College Curriculum Improvement (MC3I) | MCI is designed to strengthen STEM curricula and curricular pathways at two-year MSIs; Strengthen and diversify the STEM pipeline through high school partnerships. | Provider: All NASA Centers<br>Lead Center: Headquarters<br>Performing Center(s) All NASA Centers:<br>Cost Share Partner(s): N/A | |
| MUREP NASA Internship, Fellowship, and Scholarship (NIFS) | MUREP NIFS provides historically underrepresented groups in STEM fields and students at MSIs the opportunity to use NASA facilities and assets to provide work experiences and research and educational opportunities to improve retention in STEM and prepare students for employment in NASA STEM jobs. | Provider: All NASA Centers<br>Lead Center: JSC, Ames Research Center<br>Performing Center(s): All NASA Centers<br>Cost Share Partner(s): N/A | |
| MUREP for American Indian and Alaskan Native STEM Engagement (MAIANSE) | MAIANSE provides opportunities for TCU students, faculty and staff; and high school students who are likely to matriculate at TCUs, to engage in NASA-related STEM scientific research and engineering activities. | Provider: All NASA Centers<br>Lead Center: Goddard Space Flight Center<br>Performing Center(s): All NASA Centers<br>Cost Share Partner(s): N/A | |

# MINORITY UNIVERSITY RESEARCH EDUCATION PROJECT

| Formulation | Development | Operations |
|---|---|---|

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| MUREP Educator Institutes (MEI) | MEI is designed to develop, promote, or utilize new, innovative, and replicable approaches to improving STEM learning and instruction; Provide experiences and activities that are grounded in education research or use evidence-supported approaches, techniques, and tools; and build linkages and connections to and from secondary education, elementary education, middle school education, and higher education. | Provider: All NASA Centers<br>Lead Center: Stennis Space Center<br>Performing Center(s): All NASA Centers<br>Cost Share Partner(s): N/A | |
| MUREP STEM Engagement (MSE) | MSE gives MSIs the opportunity to design, develop, and implement a NASA-related STEM challenge targeted for MSI and community college STEM-enrolled students. All challenges align with the NASA mission and a specific NASA program or project. MSIs develop and implement processes to capture the impact of activities and strategies implemented through this challenge participation. | Provider: All NASA Centers<br>Lead Center: KSC<br>Performing Center(s): All NASA Centers<br>Cost Share Partner(s): N/A | |
| ESTEEM | ESTEEM increases the level of climate literacy and engagement of the United States public; advance the understanding of how to effectively teach global climate change concepts; and create a diverse, highly skilled, and motivated future workforce in climate-related sciences. | Provider: All NASA Centers<br>Lead Center: LaRC<br>Performing Center(s): All NASA Centers<br>Cost Share Partner(s): N/A | |

# MINORITY UNIVERSITY RESEARCH EDUCATION PROJECT

| Formulation | Development | Operations |
|---|---|---|

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| MUREP Aerospace Academy (MAA) | MAA educates students using a STEM curriculum that meets national math, science, and technology standards aligned to NASA's Mission Directorates. | Provider: All NASA Centers<br>Lead Center: GRC<br>Performing Center(s): All NASA Centers<br>Cost Share Partner(s): N/A | |

## Acquisition Strategy

MUREP solicits new and innovative education products, tools, and services from qualified MSIs and nonprofit organizations. This occurs in response to changes in STEM education trends, identified gaps, or opportunities in the education portfolio of investments, demonstrated customer need or demand, or when the Administration or Congress identifies new priorities. NASA awards education cooperative agreements, grants and contracts through full and open competition.

### MAJOR CONTRACTS/AWARDS

None.

### INDEPENDENT REVIEWS

All MUREP activities document performance through either external evaluations or internal reviews conducted by NASA staff. For example, a Technical Review Committee, made up of NASA and industry engineers and scientists, review each research awardee annually during the five-year performance period. Renewal packages for individual grantees include all relevant reports.

In 2015, MUREP reviewed two elements of the portfolio using the techniques of social network analysis. An evaluator at Science Systems and Applications, Inc., in Hampton, VA, under a contract through NASA LaRC conducted the review. The first review focused on identifying collaborations and partnerships across the portfolio of MUREP awardee institutions that received funding support in fiscal years 2011 through 2014. This process identified 366 institutions or organizations contributing to MUREP activities during that period, including 149 minority-serving institutions. The second review focused specifically on MUREP's student support activities, currently part of the NASA OE's NIFS line of business. This review compared student opportunities through MUREP funding in academic years 2010-2011, 2011-2012, and 2012-2013 to similar opportunities in 2013-2014, 2014-2015, and 2015-2016. In particular, this review focused on MUREP's reach to students who attend eligible minority serving institutions and identified a striking increase in participation beginning in academic year 2014-2015. These reviews highlighted a need for greater communication and knowledge transfer between and among MUREP activities in order to better leverage partner contributions. It also identified MSI types MUREP activities could target (HSIs, AIANSIs, and PBIs).

# STEM EDUCATION AND ACCOUNTABILITY PROJECTS

| Formulation | Development | Operations |
|---|---|---|

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **29.0** | **--** | **37.1** | **39.1** | **41.1** | **43.2** | **45.3** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**Mike Foreman signed autographs at GRC's third annual National Lab Day on May 22, 2015. He gave a thrilling presentation about his experiences as Space Shuttle Astronaut to a group of 300 middle school students. Additionally, Mike made the day for one excited young fan (pictured in front) who is anxious to show off the autograph she just received. National Lab Day engaged students in presentations, research demonstrations, hands-on activities, and lab tours throughout the day.**

SEAP uses competition to support only the most meritorious education functions, assets, and efforts of the Offices of Education at NASA Centers and JPL, Aeronautics Research Mission Directorate and Human Exploration and Operations Mission Directorate.

SEAP enhances coordination with other agencies that focus on those areas of STEM education where the Federal government can have maximum impact, including innovations in performance monitoring, evaluation and formal and informal education. The STEM Education and Accountability Projects portfolio of diverse activities directly responds to NASA's Strategic Objective 2.4: Advance the Nation's STEM education and workforce pipeline by working collaboratively with other agencies to engage students, teachers, and faculty in NASA's missions and unique assets. Specific activities funded by SEAP have goals designed to advance the Federal STEM Education five-year Strategic Plan prepared by the National Science and Technology Council's CoSTEM, addressing one or more STEM Education Priority Investment Area(s) and/or Implementation of the Coordination Objective(s).

SEAP is the result of NASA continuing to streamline and competitively consolidate its STEM education activities, consistent with Congressional and Administration direction. Working in collaboration with other Federal agencies, particularly the USDA, NSF, Smithsonian Institution, and Department of Education, NASA continues to support STEM activities across four lines of business: 1) educator professional development, 2) STEM engagement, 3) institutional engagement, and 4) internships, fellowships and scholarships. NASA's business lines provide opportunities to educators and learners, including women, minorities, and persons with disabilities.

# STEM Education and Accountability Projects

| Formulation | Development | Operations |
|---|---|---|

## Explanation of Major Changes in FY 2017

None.

## Achievements in FY 2015

- Approximately 828,000 elementary and secondary students participated in NASA instructional and enrichment activities.
    - Of those students, NASA engaged more than 39,000 in the fifth and final year of the Summer of Innovation pilot, launched in 2010 to support the President's "Educate to Innovate" initiative.
- In September 2015, after competitive selection in June as SEAP's top institutional engagement priority, NASA's OE, in cooperation with Headquarters' Offices of Communications, Diversity and Equal Opportunity, Chief Scientist, and Chief Technologist, and all the agency's Mission Directorates issued the Competitive Program for Science Museums, Planetariums, and NASA Visitor Plus Other Opportunities (NRA NNH15ZHA001N). The NRA fully aligns to the NASA and Federal STEM five-year Strategic Plan; and sets new, minimum standards for NASA recipients' evaluation activities. Proposers must describe the conduct of an independent evaluation in order to improve or assess the effectiveness of proposed strategies that advance the Nation's STEM education or workforce, including a dedicated budget.
    - More than 105 youth-serving organizations, museums, planetariums, NASA visitor centers, and other potential proposers from the District of Columbia, Puerto Rico and 36 states dialed into the NRA's pre-proposal telecon.
- The One-Stop Shopping Initiative received more than 33,000 undergraduate, graduate, and high school student applications for NASA-unique internships, fellowships, and scholarships. From this pool of exceptional talent, NASA Education was able to support 1,717 students via a NASA-unique fellowship, internship, or scholarship opportunity.
- In addition to the 40 Education no-exchange-of-funds Space Act agreements, NASA Education also supported education-related partnerships made by other NASA organizations, including Headquarters' Communications. One such agreement with Fox US Productions 38, Inc. supported the feature film The Martian. In September 2015, NASA Education's Digital Learning Network reached over 12,000 students and teachers from around the United States and seven countries for an interactive visit with The Martian's author Andy Weir, NASA experts and movie actors.

## Work in Progress in FY 2016

NASA continues to implement the results of a competition across the Mission Directorates, NASA Offices of Education at the Centers, and JPL. The 2015-2016 Priorities Competition for SEAP used criteria in an i-RFI. The initial i-RFI for SEAP used the following broad criteria: 1) Background; 2) Focus; and 3) Evidence of Effectiveness. The SEAP i-RFI ensured all submitters answered the same items and identified the priorities for selection. For a copy of the i-RFI, go to http://www.nasa.gov/sites/default/files/atoms/files/nasa_fy15_fy16_seap_priorities_competitionfinal.pdf.

# STEM EDUCATION AND ACCOUNTABILITY PROJECTS

| Formulation | Development | Operations |
|---|---|---|

The i-RFI determined the universe of priorities SEAP should select for FY 2016 funds. In brief, the selected activities most directly align to four of the five Federal STEM Education Five-Year Strategic Plan Priority Investment Area(s):

- Increase and Sustain Youth and Public Engagement in STEM
- Improve STEM Instruction
- Enhance STEM Experience of Undergraduate Students
- Better Serve Groups Historically Underrepresented in STEM Fields

SEAP selections also respond to the Federal STEM Education's Five-Year Strategic Plan's Implementation of the Coordination Objectives:

- Build New Models for Leveraging Assets and Expertise
- Build and Use Evidence-based Approaches

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

In 2017, NASA will make new commitments based on the competitive acquisition strategy described below. SEAP will execute a new internal-to-NASA competition in FY 2017. Education Offices at NASA Centers, including Jet Propulsion Laboratory, and previously funded evidence-based activities will be eligible to compete for new or follow-on SEAP funding. The winners of the SEAP competition reflect the best that NASA has to offer to the Nation's STEM enterprise. For SEAP's most current competitive achievements aligned to NASA Education's four business lines and the CoSTEM Plan, go to http://www.nasa.gov/offices/education/about/seap-activities.html.

## Project Schedule

- Over the past three years, NASA worked with CoSTEM to finalize criteria for success, develop common evidence standards, identify evaluation and research toolkits, and pursue efficiencies and collaborative opportunities consistent with the NSTC five-year Federal STEM Education Strategic Plan.
- In years four and five of the NSTC five-year Federal STEM Education Strategic Plan, the Agency continues to increase alignment with the adopted criteria.

The FY 2017 SEAP competition will identify, prioritize, and select activities that are evidence-based, show evidence of effectiveness, and capitalize on the excitement of NASA's STEM, including problem based learning. The results may be available as early as the second quarter of FY 2017. As of the date of this document, the NASA's Education Coordinating Council began preliminary deliberations regarding a second SEAP competition and how to improve Centers and NASA Mission Directorates coordination in the development of concepts, logic models, and estimated price reports.

# STEM EDUCATION AND ACCOUNTABILITY PROJECTS

| Formulation | Development | Operations |
|---|---|---|

| Date | Significant Event |
|---|---|
| On-going throughout FY 2018 | NSTC Committee on STEM Meetings |

## Project Management & Commitments

The lines of business managers (LOBs) for educator professional development, internships, fellowships and scholarships, STEM engagement and institutional engagement are located at NASA Headquarters and provide oversight for strategic activities and operations. The table below illustrates some cooperative agreements or contracts awarded in prior years.

| Element | Description | Provider Details | Change from Formulation Agreement |
|---|---|---|---|
| Cooperative Agreement Number:<br>NNX13AJ37A | Cooperative Agreement Selection Under the Cooperative Agreement Notice issued by OE NASA Internships<br>Solicitation number: NNJ13ZBR001C | Provider: Universities Space Research Association<br>Lead Center: Headquarters<br>Performing Center(s): All<br>Cost Share Partner(s): Not Applicable | No change Cooperative Agreement expires May 2018<br>Performance start date: May 2013 |
| Contract Number:<br>C13-012 | The NASA Glenn Education Support Services contract will help advance high-quality STEM education in Cleveland, NASA Headquarters in Washington, and other NASA centers, as necessary. | Provider: Paragon-TEC, Inc. of Cleveland<br>Lead Center: GRC<br>Performing Center(s): All<br>Cost Share Partner(s): Not Applicable | No Change<br>Contract expires March 2018<br>Performance start date: April 2013 |

## Acquisition Strategy

Consistent with existing NASA practices, NASA uses cooperative agreements, grants, and contracts through full and open competitions when necessary. External and internal experts base selections in part on peer reviews, In FY 2016 NASA selected activities via the FY 2015 internal-to-NASA SEAP competition.

### MAJOR CONTRACTS/AWARDS

None.

# STEM EDUCATION AND ACCOUNTABILITY PROJECTS

| Formulation | Development | Operations |
| --- | --- | --- |

## INDEPENDENT REVIEWS

NASA's primary approach to independent reviews is informed by the five-year Federal Strategic Plan and reports from the NSTC CoSTEM (Progress Report on Coordinating Federal STEM Education, March 2015) (For more information, go to https://www.whitehouse.gov/sites/default/files/microsites/ostp/stem_ed_budget_supplement_fy16-march-2015.pdf. NASA also relies on third-party reports conducted by the agency's Office of Inspector General and the Government Accountability Office.

NASA embeds evaluation and accountability requirements within SEA activities as appropriate for performance monitoring. In October 2015 the NASA Office of Inspector General issued its report No. IG-16-001 measuring the performance of NASA's Education Program. The OIG's report states that they "initiated this audit to examine NASA's education activities and determine whether the Agency was effectively implementing its education objective and Federal STEM education priorities." The OIG found that "NASA's OE has taken steps to improve its management of the Agency's diverse education portfolio by restructuring several programs and projects to better align with Federal guidance." The OIG also found that: "the OE has developed a competitive process for identifying effective STEM education activities that deserve funding, NASA can further improve its processes and procedures to collaborate and consolidate education activities. In response to an OMB requirement that NASA's internal projects and activities compete with one another for education funding, in FY 2015 the OE initiated an internal, criteria-based competition as the basis for its funding prioritization process." NASA agreed to corrective actions related to five OIG recommendations and the agency's response noted: "NASA recognizes this audit as a progress report on the agency's on-going restructure of its Education portfolio, including performance measurement reporting conducted by the OE. NASA also appreciates that the OIG's draft report documents NASA's education investment and ways that investment contributes to Federal STEM Education Five-Year Strategic Plan, a priority for the Obama Administration." (For the full report and agency response, go to https://oig.nasa.gov/audits/reports/FY16/IG-16-001.pdf.).

The contractor, Paragon TEC, conducted a study of the FY 2015 collaboration between NASA and the Department of Education as explained below. For a full copy of this study entitled, STEM Design Challenges for 21st Century Community Learning Centers (21CCLC) Final Evaluation Report, go to http://www.nasa.gov/sites/default/files/atoms/files/21cclc-middle_school-final-report.pdf.

| Review Type | Performer | Date of Review | Purpose | Outcome | Next Review |
| --- | --- | --- | --- | --- | --- |
| Implementation evaluation study | Paragon TEC | Jan – May 2014 | Conduct a third-party formative evaluation that documents implementation and preliminary impacts of NASA STEM Challenges within Department of Education's 21CCLC program | The report provides 12 evidence-based observations for how new NASA STEM Challenges within Department of Education's 21CCLC program could be improved. | No further action due to the expiration of the reimbursable Space Act Agreement with the Department of Education. |

# SAFETY, SECURITY, AND MISSION SERVICES

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Center Management and Operations | 2023.7 | -- | **2017.7** | 2058.1 | 2113.5 | 2155.6 | 2198.8 |
| Agency Management and Operations | 730.9 | -- | **819.2** | 835.5 | 838.0 | 854.8 | 871.8 |
| **Total Budget** | **2754.6** | **2768.6** | **2836.8** | **2893.6** | **2951.5** | **3010.4** | **3070.6** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

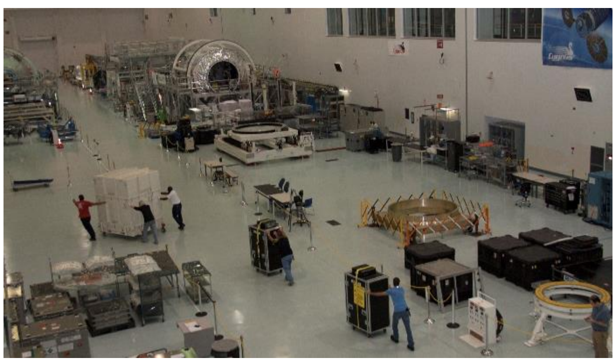
# SAFETY, SECURITY, AND MISSION SERVICES

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Center Management and Operations | 2023.7 | -- | **2017.7** | 2058.1 | 2113.5 | 2155.6 | 2198.8 |
| Agency Management and Operations | 730.9 | -- | **819.2** | 835.5 | 838.0 | 854.8 | 871.8 |
| **Total Budget** | **2754.6** | **2768.6** | **2836.8** | **2893.6** | **2951.5** | **3010.4** | **3070.6** |
| Change from FY 2016 | | | **68.2** | | | | |
| Percentage change from FY 2016 | | | **2.5%** | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**NASA workforce and facilities provide the tools and services needed to conduct its mission. Above, workers at NASA's Kennedy Space Center (KSC) in Florida navigate the newly arrived SAGE-III instruments through the aisles of the Space Station Processing Facility to begin preparing for launch to the International Space Station (ISS) next year. Photo credit: NASA/Charles Babir**

Safety, Security, and Mission Services (SSMS) activities manage the administration of the Agency; operate and maintain NASA centers and facilities, including Headquarters; and provide oversight to reduce risk to life and mission for all NASA programs.

SSMS provides both institutional and program capabilities for the Agency. Institutional capabilities ensure that Agency operations are effective, efficient, and meet statutory, regulatory, and fiduciary responsibilities. Program capabilities ensure that technical skills and assets are ready and available to meet program and project milestones; that missions and research are technically and scientifically sound; and that Agency practices are safe and reliable. Together, these capabilities sustain 4,400 buildings and structures on 330,000 acres across the Agency's centers and facilities.

Missions rely on SSMS program and institutional capabilities to accomplish their objectives. Engineering, systems engineering, and safety and mission assurance capabilities support technical activities. IT, infrastructure, and security capabilities support the productivity of NASA scientists and engineers. Human capital management, finance, procurement, occupational health and safety, equal employment opportunity and diversity, and small business programs contribute to the strategic and operational planning and management that ensure resources are available when needed. International and interagency relations, legislative and intergovernmental affairs, and strategic communications facilitate communications with a broad range of external communities. These program and institutional capabilities and related processes speak to the complexity of the support necessary for successful NASA missions and safe Agency and Center operations.

# SAFETY, SECURITY, AND MISSION SERVICES

## EXPLANATION OF MAJOR CHANGES IN FY 2017

NASA is transferring $44.9 million for existing network operations to Agency IT Services (AITS) from Center Management and Operations, Mission Directorates, and Agency Management to consolidate network operations, IT network transformation, and voice services under the Agency CIO. This IT funding already existed under multiple accounts but is being consolidated into one program. This transfer will improve network transformation and IT security while reducing redundancy and inefficiencies.

The FY 2017 request includes investments in critical IT infrastructure and enterprise solutions. Funding will support modernizing Agency systems, increased automation, and optimized delivery of enterprise-wide IT service solutions.

## ACHIEVEMENTS IN FY 2015

NASA is working to instill a culture of innovation in its workforce by recognizing and rewarding innovative performance; engaging and connecting the workforce to make it easy for employees to collaborate, network, and innovate; and creating an environment in which leaders view developing innovative employees as a productive and vital use of their time. SSMS activities provide the facilities, tools, and services needed to conduct NASA's missions safely and effectively. For example, in FY 2015, NASA:

- Continued to lead the Federal Government in employee engagement, as demonstrated by the results of the 2015 Federal Employee Viewpoint Survey (FEVS). NASA is one of three agencies with the highest employee engagement score for a large agency, having increased its employee engagement score over the last six years, from 76 percent in 2010 to 78 percent in 2015. Successful agencies foster an engaged working environment that ensures that each employee can reach his or her potential and contribute to the success of the Agency;
- As reported on the 2015 Scorecard on Sustainability/Energy, NASA generated 8.9 percent of its electricity from renewable energy sources, exceeding the target of 7.5 percent. NASA accomplished this goal by generating on-site renewable energy, purchasing green power, and purchasing renewable energy credits;
- Assured the safety and health of its activities. NASA's Total Case Rate and Lost Time Case Rate were under the injury and illness goals established in the President's Protecting Our Workers and Ensuring Reemployment (POWER) initiative;
- Completed the planned set of upgrades for the Security Operations Center (SOC) at the Ames Research Center (ARC). The upgrades spanned 27 Intrusion Detection Systems, increasing the Agency's readiness to combat cyber threats. These technology upgrades improve the SOC's capability to detect and prevent security incidents, increasing the ability to analyze system and network vulnerabilities across the enterprise as compared to known and evolving cyber threats;
- Met the goal of 100 percent personal identity verification (PIV) use for privileged account access and 75.0 percent PIV use for non-privileged access in FY 2015; and
- Initiated the Business Services Assessment (BSA) process by completing a comprehensive review of the Agency's IT services. By engaging the Mission Support functions through the BSA, NASA is defining the health of selected business service areas; identifying opportunities for optimization; and developing risk-informed recommendations. Implementation of the improvements identified through the IT BSA is underway.

# SAFETY, SECURITY, AND MISSION SERVICES

## WORK IN PROGRESS IN FY 2016

SSMS continues its crosscutting support of the Agency's aeronautics and space activities, using innovative approaches to provide the required programmatic, business, and administrative capabilities. Key activities underway include:

- Implementing improvements from the BSA of IT and completing assessments of acquisition, human capital management, budget management, and facilities management.
- Assessing high pressure layered pressure vessels to evaluate material fracture properties, vessel analysis methodologies, and inspection techniques, to ensure that unsafe vessels are identified in time to prevent excessive risk to personnel; and
- Implementing key findings and recommendations from the National Research Council study (Limiting Future Collision Risk to Spacecraft: An Assessment of NASA's Micrometeoroid Orbital Debris Programs on micrometeoroid and orbital debris

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

In FY 2017, SSMS programs will continue to balance the risks across center and Agency services and activities to provide a safe, reliable infrastructure to conduct NASA's aeronautics and space activities. SSMS programs will:

- Implement long-term changes identified through the BSAs of acquisition, human capital management, budget management, and facilities management to optimize services, and maintain a minimum set of capabilities to meet mission needs.
- Continue to improve the Agency's information security posture and assure NASA's IT systems and networks support the Agency's critical missions;
- Operate and maintain NASA Centers and major component facilities to ensure a safe, healthy, and environmentally responsible workplace;
- Provide essential operations such as Center security, environmental management, safety services, and facility maintenance;
- Support the workforce with utilities, IT, legal, occupational health, equal employment opportunity, financial management, and human resources services;
- Provide the technical facilities, workforce expertise and skills, equipment, and other resources required to implement the program at the Center; and
- Ensure engineering and safety oversight of NASA's programs.

# Themes

## CENTER MANAGEMENT AND OPERATIONS

CMO provides the ongoing management, operations, and maintenance of NASA Centers and component facilities in nine states. Missions rely on the Centers to provide the skilled staff and specialized infrastructure required to accomplish their objectives.

# SAFETY, SECURITY, AND MISSION SERVICES

## AGENCY MANAGEMENT AND OPERATIONS

AMO provides management and oversight of Agency missions and performance of NASA-wide mission support activities. AMO activities at NASA Headquarters ensure that core services are ready and available across the Agency for performing mission roles and responsibilities.

# CENTER MANAGEMENT AND OPERATIONS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Center Institutional Capabilities | 1574.8 | -- | **1563.8** | 1596.7 | 1636.9 | 1665.1 | 1696.1 |
| Center Programmatic Capabilities | 448.9 | -- | **453.8** | 461.4 | 476.6 | 490.5 | 502.7 |
| **Total Budget** | **2023.7** | -- | **2017.7** | **2058.1** | **2113.5** | **2155.6** | **2198.8** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*


**NASA Centers across the country provide the institutional and programmatic capabilities required to support the missions. In this image, technicians at the Marshall Space Flight Center (MSFC) inspect layered pressure vessels to ensure that they can safely meet mission requirements.**

NASA's CMO budget funds ongoing management, operations, and maintenance at nine Centers and three major component facilities in nine states. CMO includes two major activities: Center Institutional Capabilities and Center Programmatic Capabilities.

Missions rely on these program and institutional capabilities to provide the skilled staff and specialized infrastructure required to accomplish their objectives.

Center institutional capabilities provide the facilities, staff, and administrative support for effective and efficient NASA Center operations. These capabilities enable NASA Centers and missions to meet its statutory, regulatory, and fiduciary responsibilities.

Program capabilities support scientific and engineering activities at the Centers. These program capabilities ensure that technical skills and assets are ready and available to meet program and project milestones; that missions and research are technically and scientifically sound; and that Center practices are safe and reliable.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

Reallocates funding from CMO to AITS to consolidate network transformation, operations, and voice services under the Agency CIO.

## ACHIEVEMENTS IN FY 2015

NASA continued to improve operations to enable the Agency to conduct its day-to-day technical and business operations more effectively. For example:

- ARC completed the enrollment of assets into the new Radio Frequency Identity Detector (RFID) equipment tracking system and integrated RFID into the annual inventory process. Implementation of the RFID system will reduce property loss rates, reduce redundancy, reduce cycle time and increase inventory accuracy;
- A new financial services contract at ARC enabled the Agency to better manage overhead costs by providing an opportunity to reduce the number of financial service contracts through a consolidated contract;
- Armstrong Flight Research Center (AFRC) implemented a digital 911 system that addressed reliability issues and eliminated the maintenance requirements and costs associated with the horizontal infrastructure of the antiquated analog system;
- KSC completed outfitting and activation of KSC's data center, which is expected to reduce annual energy use and operations and maintenance costs;
- To provide for early detection and correction of facility maintenance issues, Centers continued to increase reliability-centered maintenance and condition-based monitoring activities. Efficient maintenance through the expansion of the existing Condition Based Maintenance Program at Stennis Space Center (SSC) and similar activities Agency-wide reduced maintenance requirements and facilitated correction of maintenance problems before costly failures occurred; and
- KSC entered into a Federal-State Partnership Agreement with Space Florida for the transfer, management, development, and operations of property and infrastructure comprising the Shuttle Landing Facility.

## WORK IN PROGRESS IN FY 2016

In FY 2016, Centers are providing the essential day-to-day technical and business operations required to conduct NASA's aeronautics and space mission activities. Activities encompass the services, tools, and equipment required to complete essential tasks, protect and maintain the security and integrity of information and assets, and ensure that personnel work under safe and healthy conditions. Efforts underway include:

- Focus on employee engagement and development to attract and advance the highly skilled and diverse workforce needed to conduct NASA's mission. Resources, such as the Goddard Space Flight Center (GSFC) web-based career path site for employees provides a high-level view of career development paths for all employees and increases awareness of developmental opportunities;
- SSC completes construction on a Utility Energy Service Contract through the Department of Energy's Federal Energy Management Program. The program allows federal agencies to partner with utility companies to achieve energy and cost savings by implementing energy conversation projects. Energy cost savings funds the project, thereby reducing the need for federal funding. The planned benefits include streamlined procurement, flexible contracts, and payments via the utility bills;
- Glenn Research Center (GRC) Lewis Field completes the installation of new Voice over IP (VoIP) phone system. This eliminates the risk of a phone system failure from the current legacy system; and
- SSC transitions to a new facility operations support contract, which will support both SSC and MSFC's Michoud Assembly Facility. The consolidated contract leverages the synergies between the sites to reduce overall costs.

# CENTER MANAGEMENT AND OPERATIONS

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

Centers will provide the services, tools, and equipment to complete essential tasks, protect, and maintain the security and integrity of information and assets, and ensure that personnel work under safe and healthy conditions. In FY 2017, CMO will support:

- Facility maintenance and operations; including: utility and custodial support of approximately 4,400 buildings and structures with a current total replacement value of $34 billion (82 percent of NASA's assets by value are beyond their design life);
- IT activities for video, voice, network, IT security, and desktop support at Centers;
- Institutional operational safety support to protect personnel and assets, aviation safety, emergency preparedness, nuclear safety, construction safety, and other safety services;
- Physical security, fire protection and response, emergency management, export control, and other basic and specialized protective services;
- Compliance with environmental regulations, executive orders, and related requirements to protect human health and the environment;
- Human resource management; including: recruitment, hiring, workforce planning, training, and performance management supporting approximately 16,100 civil servants at the Centers;
- Occupational and environmental health and medical support such as: industrial hygiene, health physics, hearing conservation, and licensed and credentialed medical personnel and facilities to meet specialized mission requirements;
- Personal property management, transportation management, mail management, and other logistical support;
- Duplicating and printing support, video production, audio/visual services, and publications and graphics (includes specialized support for the production and archiving of scientific and technical information);
- Senior leadership and management of the Centers, executive staff and administrative support, student programs, and developmental assignments;
- Routine public affairs activities, dissemination of information about NASA programs and projects to the general public, and responses to public inquiries;
- Administration and management of Center financial operations;
- Acquisition and contract management capabilities and practices supporting 41,000 procurement actions each year;
- Engineering assessment and safety oversight pertaining to the technical readiness and execution of NASA programs and projects; and
- Analysis, design, research, test services, and fabrication capabilities to enable efficient implementation of the programs and projects.

# Program Elements

## CENTER INSTITUTIONAL CAPABILITIES

Center Institutional Capabilities encompasses a diverse set of activities essential for safe and effective operations. These activities provide the ongoing operations of NASA Centers and major component facilities and ensure a safe, healthy, and environmentally responsible workplace. Included are essential operations such as Center security, environmental management and safety services, and facility maintenance and operations. To support the Agency's Center-based workforce, Center Institutional Capabilities provide utilities, IT, legal, occupational health, equal employment opportunity, and human resources services. This capability manages and sustains Center staff, facilities, and operations.

## CENTER PROGRAMMATIC CAPABILITIES

NASA's Center Programmatic Capabilities supports the Agency's scientific and engineering activities by providing engineering assessment and safety oversight pertaining to the technical readiness and execution of NASA programs and projects. It also sustains NASA's analysis, design, research, test services, and fabrication capabilities to enable efficient implementation of the programs and projects conducted at the Centers.

Center Programmatic Capabilities provide a key component of NASA's overall system of checks and balances. The engineering, safety and mission assurance, and health and medical organizations at the Centers: (1) provide, support, and oversee the technical work, and (2) provide formally delegated Engineering (Figure 1) and Safety and Mission Assurance Technical Authorities (Figure 2) at NASA Centers. These technical authorities provide independent oversight and review of programs and projects in support of safety and mission success. Cognizant technical authorities formally review and concur on technical and operational matters involving safety and mission success risk. These technical authorities concur based on the technical merits of each case and agreement that the risks are acceptable. This assures that NASA conducts its mission activities safely in accordance with accepted standards of professional practice and applicable NASA requirements.

**Engineering Technical Authorities**

| **Center** | **FY 2017 $ in millions** |
|---|---|
| Ames Research Center | $7.7 |
| Armstrong Flight Research Center | $8.0 |
| Glenn Research Center | $12.8 |
| Goddard Space Flight Center | $12.9 |
| Johnson Space Center | $22.6 |
| Kennedy Space Center | $14.9 |
| Langley Research Center | $17.2 |
| Marshall Space Flight Center | $37.7 |
| Stennis Space Center | $3.5 |
| **Grand Total** | **$137.3** |

*Figure 1: Engineering Technical Authorities provide independently funded engineering assessment of programs*

**Safety and Mission Assurance Technical Authorities**

| **Center** | **FY 2017 $ in millions** |
|---|---|
| Ames Research Center | $3.4 |
| Armstrong Flight Research Center | $4.2 |
| Glenn Research Center | $2.6 |
| Goddard Space Flight Center | $12.4 |
| Johnson Space Center | $6.4 |
| Kennedy Space Center | $9.0 |
| Langley Research Center | $3.0 |
| Marshall Space Flight Center | $8.2 |
| Stennis Space Center | $2.1 |
| **Grand Total** | **$51.3** |

*Figure 2: Safety and Mission Assurance Technical Authorities provide independently funded safety assessment of programs*

# AGENCY MANAGEMENT AND OPERATIONS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Agency Management | 363.6 | -- | **377.5** | 385.1 | 395.6 | 403.5 | 411.6 |
| Safety and Mission Success | 164.9 | -- | **170.4** | 173.8 | 178.5 | 182.1 | 185.7 |
| Agency IT Services (AITS) | 175.5 | -- | **244.3** | 249.1 | 235.6 | 240.3 | 245.0 |
| Strategic Capabilities Asset Program | 26.9 | -- | **27.0** | 27.5 | 28.3 | 28.9 | 29.5 |
| **Total Budget** | **730.9** | **--** | **819.2** | **835.5** | **838.0** | **854.8** | **871.8** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**NASA has been investing significantly in cybersecurity capabilities to manage risk and mitigate cyber threats. NASA continues to improve cybersecurity by preventing malicious cyber activity, enhancing the protection of NASA's Federal systems and information, and strengthening cybersecurity awareness across NASA's workforce.**

AMO provides management and oversight of Agency missions and performance of NASA-wide mission support activities. AMO activities at NASA Headquarters ensure that core services are ready and available, Agency-wide, for performing mission roles and responsibilities and that Agency operations are effective and efficient and meet statutory, regulatory, and fiduciary requirements.

NASA Headquarters develops policy and guidance for the Centers and provides strategic planning and leadership. Headquarters establishes Agency-wide requirements and capabilities that improve collaboration, efficiency, and effectiveness. Agency management leverages resources and capabilities to meet mission needs, eliminate excess capacity, and scale assets accordingly.

AMO provides for policy-setting, executive management, and direction for all corporate functions. AMO supports the operational costs of the Headquarters installation. The AMO theme consists of four programs: Agency Management, Safety and Mission Success (SMS), AITS, and Strategic Capabilities Asset Program (SCAP).

## EXPLANATION OF MAJOR CHANGES IN FY 2017

As discussed under Center Management and Operations, NASA is transferring existing activities and associated funding to AITS from Center Management and Operations, Mission Directorates, and Agency Management to consolidate network operations, transformation, and voice services under the Agency CIO.

# AGENCY MANAGEMENT AND OPERATIONS

## ACHIEVEMENTS IN FY 2015

NASA maintained its position as the top large agency in the 2015 rankings as the Best Place to Work in the Federal Government, improving our employee satisfaction and commitment score by focusing on three key priority areas: connecting people to each other and the mission; building model supervisors; and recognizing and rewarding innovative performance.

As a result of building renovations, NASA's Headquarters office building achieved Leadership in Energy and Environmental Design (LEED) Gold certification in August 2015. This certification surpasses the original target of Silver LEED certification.

SMS conducted 11 formal, stringent Safety and Mission Success Reviews. These reviews are the culmination of the identification and mitigation of all potential Safety and Mission Assurance (SMA) problems for launches and high criticality events. The NASA Safety Center conducted 14 audits, assessments, and reviews at eight separate NASA Centers and component facilities in FY 2015. A total of 223 findings were documented that included potential systemic issues, critical concerns, non-compliances, observations, commendations, and best practices.

NASA released over 30,000 datasets and 40 application programming interfaces (APIs) during FY 2015 through its public online portal at https://data.nasa.gov/, supporting the Federal Cross-Agency Priority Goal to open government data.

NASA completed the planned set of upgrades for the SOC at the ARC increasing the Agency's readiness to combat cyber threats.

NASA met the goal of 100 percent PIV use for privileged account access and 76.7 percent PIV use for non-privileged access in FY 2015.

For the fifth consecutive year, the Agency received a clean (unmodified) audit opinion of its accounting and financial systems.

## WORK IN PROGRESS IN FY 2016

The SMA program will continue to advance NASA's capabilities to mitigate and remove on-orbit debris, reduce hazards, and increase the understanding of the current and future orbital debris environment. SMA will also continue to advance its program to detect, track, catalog, and reduce the number of counterfeit electronic parts in the NASA supply chain.

In FY 2016, the Independent Verification and Validation (IV&V) Program is providing software expertise to 17 projects, including 13 NASA missions, the Commercial Crew Program, 3 multi-agency missions, and across 8 NASA Centers.

The NASA Engineering and Safety Center (NESC) plans to conduct over 50 independent assessments of NASA's highest risk challenges maintaining prioritization on the ISS, Commercial Crew, Orion/Space Launch System, James Webb Space Telescope (Webb), and Space Technology.

NASA will complete the Consolidated Network Operations System Project, which will standardize network operations processes and procedures across the Communications Services Office (CSO) Corporate Networks into Center operations and processes. This standardization ensures operational efficiencies by using enterprise best practices to consolidate network services and reduce duplication of effort, while improving overall end-to-end visibility of CSO-managed networks and improved IT security.

NASA will begin formulation of a project to migrate email and calendaring capabilities to a cloud-based Microsoft Office 365 infrastructure. NASA will generate target architectures, gap assessments, and capital improvement plans for enterprise communications services including wide area network, local area network, voice, and cable plant systems.

### KEY ACHIEVEMENTS PLANNED FOR FY 2017

In FY 2017, Office of Safety and Mission Assurance (OSMA) will increase efforts to examine layered pressure vessel material properties, analysis methodologies, and inspection techniques. OSMA will also develop assurance methodologies for the emerging fields of additive manufacturing.

Collaborative efforts between the Office of Chief Engineer (OCE), and Office of Chief Health Medical Office (OCHMO), and OSMA will continue to strengthen the Agency's Technical Authority capability. The offices will continue to work together conducting safety reviews and independent technical assessments of NASA's missions.

In FY 2017, NASA will continue its network transformation by transitioning to a single NASA enterprise network and effectively utilize the bandwidth of the CSO backbone for both corporate and mission data. NASA's mission services will begin transitioning to the new communications backbone, allowing for decommission of legacy transport services, resulting in cost avoidances.

The Agency will continue to improve its network security with an enterprise approach to perimeter control and maintenance, including implementation of an Enterprise Firewall and Web Content Filter, deployment of Network Access Control systems inside NASA's networks, and replacement of Center Virtual Private Networks with an enterprise PIV-enabled solution.

NASA will complete the Contract Management Transformation project, which will position the Agency for increased transparency and efficiency by enabling the Agency's ability to meet regulatory reporting and data management requirements.

NASA plans to increase the OMB-mandated inventory of open datasets. By the end of FY 2017, NASA expects to have an estimated 10,000 publications submitted for public consumption on PubMed Central.

## Program Elements

### AGENCY MANAGEMENT

Agency Management provides functional and administrative management oversight for the Agency and operational support for NASA Headquarters. Agency Management governance and oversight activities include finance, protective services, general counsel, public affairs, external relations, legislative affairs, training, human capital management, procurement, real property and infrastructure, budget management, systems support, internal controls, diversity, equal opportunity, independent program and cost evaluation, and small business programs.

# AGENCY MANAGEMENT AND OPERATIONS

## SAFETY AND MISSION SUCCESS

SMS programs protect the health and safety of the NASA workforce and improve the probability of safety and mission success for NASA's programs, projects, and operations. SMS includes NASA Headquarters programs, providing technical excellence, mission assurance, and technical authority. This includes the work managed by OSMA, IV&V, OCE, and OCHMO.

## AGENCY INFORMATION TECHNOLOGY SERVICES

AITS program is a critical enabling capability dedicated to IT excellence to ensure every mission can achieve success within NASA's complex environment. The AITS mission improves management and security of IT systems while systematically improving the efficiency, collaboration capabilities, and streamlined service delivery and visibility for the entire Agency.

## STRATEGIC CAPABILITIES ASSETS PROGRAM

SCAP ensures the essential Agency test facilities are in a state of readiness, maintains the skilled workforce, and performs essential preventative maintenance to keep these facilities available to meet program requirements. Core capabilities supported within SCAP are thermal vacuum chambers, simulators, and the Arc Jet Facility.

# AGENCY MANAGEMENT

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **363.6** | **--** | **377.5** | **385.1** | **395.6** | **403.5** | **411.6** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**NASA Headquarters in Washington, DC provides overall planning and policy direction for Headquarters and the corporate management for all of its field Centers, which includes approximately 50,000 civil servant employees, and on and near site contractors NASA-wide. NASA maintains its ranking as the top large agency as the Best Place to Work in the Federal Government.**

Agency Management provides functional and administrative management oversight for the Agency and operational support for NASA Headquarters. This program primarily supports ongoing operations. Agency Management supports the activities necessary to conduct business in the Federal sector and provides the capability to respond to legislation and other mandates. The Agency Management program supports over 35 discrete operations and mission support activities

Agency Management provides policies, controls, and oversight across a range of functional and administrative management service areas. Agency Management governance and oversight activities include finance, protective services, general counsel, public affairs, international and interagency relations, legislative affairs, training, human capital management, procurement, real property and infrastructure, budget management, systems support, internal controls, diversity, equal opportunity and small business programs. The Agency Management program supports operational activities of Headquarters as an installation. These activities include building lease costs, facility operations costs (such as physical security, maintenance, logistics, IT hardware, and software costs), automated business systems implementation, and operations costs (such as internal control initiatives related to transparency and accountability in government).

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## ACHIEVEMENTS IN FY 2015

NASA maintained its position as the top large agency in the 2015 rankings as the Best Place to Work in the Federal Government, improving our employee satisfaction and commitment score by focusing on

# AGENCY MANAGEMENT

three key priority areas: connecting people to each other and the mission, building model supervisors, and recognizing and rewarding innovative performance.

NASA completed the first round of a new development program for supervisors called "Leveraging Agency Supervisory Excellence and Resilience" (LASER). LASER is a comprehensive program that is built and designed by model Agency supervisors. The LASER program helps individual supervisors address their unique growth and development needs within the complex discipline of supervision through face-to-face weeklong development sessions, mentoring sessions with senior leaders, coaching, hands-on experiences, and peer teaching.

NASA Headquarters continued to successfully respond to Agency and Federal Data Center Consolidation initiatives by reducing its data center footprint and increasing the virtualization of services. In FY 2015, NASA retired an additional 50 physical servers and consolidated 84 services in the HQ Virtual Machine cluster. The reductions of physical servers, combined with other planned consolidation efforts, will enable Headquarters to further reduce the number of server racks in the data center in FY 2016.

NASA completed vital security upgrades to the secret level Video Teleconferencing (VTC) system. VTC allows the counterintelligence community to conduct virtual secure briefings with external agencies thereby reducing the need for travel associated with in-person conference/working group meetings.

Headquarters established an Amazon Web Services (AWS) environment that supported the provision of SharePoint 2013 collaboration services to our Headquarters customers in a Managed Cloud Environment (MCE) and enabled the migration of 19 applications (both NASA-only and publically accessible) to the cloud.

## WORK IN PROGRESS IN FY 2016

NASA's Small Business Programs Office is improving the Agency performance in small business subcategories by identifying, increasing, and promoting small business prime contracting opportunities. By the end of FY 2017, each Center will have set aside new requirements to one of three small business sub-categories including Woman-Owned Small Business (WOSB), Historically Underutilized Business Zone (HUBZone), and Service-Disabled Veteran-Owned Small Business (SDVOSB).

NASA Headquarters will enhance its continuity of operations (COOP) capabilities to provide for the continued management and operations of the Agency in the event that Agency management is not able to remain in or operate from the National Capital Region. In particular, Headquarters will be participating in the 2016 FEMA Eagle Horizon exercise that will test NASA's ability to conduct mission-essential functions and maintain effective leadership of the Agency on a "no notice" basis. Headquarters will be updating and testing policies and plans related to active shooter scenarios via simulations and drills.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA Headquarters, in concert with the General Services Administration and the District of Columbia, will complete the installation of a Level IV Physical Security perimeter at its E Street location. The Level IV Physical Security protocol includes the development and installation of bollards and benches on all sides of the building, as well as operable vehicle entry barriers at the garage and alley entrances.

# AGENCY MANAGEMENT

Agency Management will deploy Agency-wide training on Alternative Dispute Resolution (ADR). This training complies with the Equal Employment Opportunity Commission's (EEOC) Management Directive 110 (which informs managers and supervisors of the benefits of ADR utilization to mutually resolve disputes in a manner that is more efficient, cost effective and results in improved Agency productivity).

In FY 2017, the Agency will continue building a highly engaged workforce as outlined in the NASA Human Capital five-year plan. This plan outlines the three primary focus areas that have a large impact on instilling innovation within the work environment: recognizing and rewarding innovative performance, engaging and connecting the workforce, and building model supervisors and leaders. These focus areas support steps to ensure the NASA workforce is equipped to acquire new skills demanded by our mission, as well as enhance productivity and motivate employees to find new solutions.

## Program Elements

### HEADQUARTERS OPERATIONS

Headquarters Operations manages and sustains the Headquarters employees and contractors, facilities, and operations required for program and institutional execution. Areas include:

- IT and communications infrastructure hardware and software acquisitions and maintenance, as well as contracted services for IT support of the Headquarters staff;
- Facility operations support, including physical security, custodial, and maintenance services; equipment; expendable supplies; mail services; printing and graphics; motor pool operations; logistics services; and emergency preparedness;
- Human resources staffing; employee payroll and benefits processing; retirement services; employee training; employee occupational health, fitness, and medical services; and grants awards processing; and
- Headquarters operations, including support provided by GSFC for accounting and procurement operations; configuration maintenance; automated business and administrative systems; contract close-out services; and payments to the NASA Shared Services Center for grants management.

### MISSION SUPPORT

The Agency Management budget also provides for functional leadership of administrative and mission support activities at Headquarters and Centers perform this diverse set of activities on behalf of the Agency.

Mission Support activities include:

- Execution and management of the Agency's financial and budget processes and systems. This includes overseeing strategic planning, budget and financial management and accountability practices, while providing timely, accurate, and reliable information, and enhancing internal controls;
- Leadership and management of NASA protective services operations. This includes policy formulation; oversight, coordination and management of protective services operations, including

## AGENCY MANAGEMENT

security, fire, emergency management, and emergency preparedness; support for Agency counterintelligence and counter-terrorism activities; implementation of the identity, credentials and access management systems and other security systems, including communications; continuity of operations; and national intelligence community services;

- Technical expertise and oversight of Agency infrastructure and management systems for: aircraft, environmental, real property, logistics, and strategic capabilities programs; and
- Leadership and management of the Agency's human capital resources and Equal Employment Offices. These offices engage the Agency in proactive equal opportunity and diversity-inclusion initiatives, workforce development and alternate dispute resolution services and complaint investigations

# SAFETY AND MISSION SUCCESS

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Safety and Mission Assurance | 48.7 | -- | **51.2** | 52.2 | 53.6 | 54.7 | 55.8 |
| Chief Engineer | 82.6 | -- | **86.1** | 87.8 | 90.2 | 92.0 | 93.8 |
| Chief Health and Medical Officer | 4.2 | -- | **4.1** | 4.2 | 4.3 | 4.4 | 4.5 |
| Independent Verification and Validation | 29.4 | -- | **29.0** | 29.6 | 30.4 | 31.0 | 31.6 |
| **Total Budget** | **164.9** | **--** | **170.4** | **173.8** | **178.5** | **182.1** | **185.7** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**Carlie Zumwalt from the LaRC inspects a supersonic disk-gap-band (DGB) parachute model in the LaRC Transonic Dynamics Tunnel as part of the NASA Engineering and Safety Center's Subscale Low Density Supersonic Parachute Wind-Tunnel Test. NASA has used the DGB parachute design on all US missions to Mars, since the 1976 Viking Project, to decelerate robotic payloads in the planet's thin atmosphere.**

SMS programs protect the health and safety of the NASA workforce and improve the likelihood that NASA's programs, projects, and operations will be completed safely and successfully. SMS includes programs that provide technical excellence, mission assurance, and technical authority. It also includes work managed by OSMA, including the NASA Safety Center and IV&V; OCE including the NASA Engineering and Safety Center; and OCHMO. The elements of SMS reflect the recommendations outlined in many studies and by advisory boards and panels. These programs directly support NASA's core values and serve to improve the probability of safety and mission success for NASA's programs, projects, and operations while protecting the health and safety of NASA's workforce.

SMS develops policy and procedural requirements. This program results in recommendations to the Administrator, mission directorates, Center Directors, and program managers who ultimately are responsible for the safety and mission success of all NASA activities and the safety and health of the workforce. SMS resources provide the foundation for NASA's system of checks and balances, enabling the effective application of the strategic management framework and the technical authorities defined in NASA's Strategic Management and Governance Handbook. SMS funds provide training and maintain a competent technical workforce within the disciplines of system engineering, including system safety, reliability, and quality, as well as space medicine.

SMS resources are essential for evaluating the implications on safety and mission success, including the health and medical aspects of new requirements and departures from existing requirements. With this funding, discipline experts analyze the criticality of the associated risks and evaluate the risks' acceptability through an established process of independent reviews and assessments. The information and advice from these experts provide critical data required by the technical authorities to develop authoritative decisions related to the application of requirements on programs and projects.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## ACHIEVEMENTS IN FY 2015

SMS conducted 11 formal, stringent Safety and Mission Success Reviews. These reviews are the culmination of the identification and mitigation of all potential SMA problems for launches and high criticality events. Substantive participation in Directorate Program Management Council (DPMC), Flight Planning Boards, Key Decision Point reviews, and selected lower level reviews and assessments collectively enable effective governance and successful mission implementation.

NASA and the Air Force Research Laboratory (AFRL) deployed a 1.3-meter aperture telescope on Ascension Island for space debris research in 2015. The telescope is undergoing testing and is progressing towards routine operations.

OSMA provided policy direction, functional oversight, and assessment for all Agency safety, reliability, maintainability, and quality engineering and assurance activities. This office served as the principal advisory resource for the Administrator and other senior officials on matters pertaining to safety and mission assurance. In FY 2015, OSMA successfully executed these functions and enhanced its efforts to assess and communicate the health of safety and mission assurance throughout the Agency in support of NASA's strategic goals and governance approach.

OSMA updated five Agency-level directives/standards. Significant changes included updating the NASA requirements for ground-based pressure vessels and pressurized systems; lifting standards; fiber optic termination, cable assemblies, and installation; and the NASA expendable launch vehicle payload safety requirements. OSMA updated and vetted each of these documents to ensure requirements were clear, necessary, and supported NASA's mission.

The NASA Safety Center conducted 14 audits, assessments, and reviews at eight separate NASA Centers and component facilities in FY 2015. The audit and assessment program categorizes findings that provide NASA installations opportunities to improve the safety and quality of their operations and activities. NASA programs and projects at these locations are reviewed to optimize and enhance their safety and quality assurance accomplishments. During the fiscal year, the NASA Safety Center documented 223 findings that included potential systemic issues, critical concerns, non-compliances, observations, commendations, and best practices.

NASA's IV&V Program provided software expertise to 18 projects and 8 NASA Centers. The IV&V Program uses a rating system for issues identified in software artifacts. The issue ratings range from 1 to 5. A '1 rating' indicates that if the issue were to manifest itself during spacecraft or system operations, NASA could experience loss of life, physical injury, and/or mission failure. In FY 2015, the IV&V Program identified and documented 49 issues with a rating of one. Resolution of these issues were completed.

# SAFETY AND MISSION SUCCESS

OCHMO sought new ways to utilize the data contained within the Electronic Health Records System (EHRS) at all NASA Centers. The EHRS allows NASA to efficiently access and analyze medical records for employees across the Agency, thereby enhancing the effectiveness of preventive health assessments and Occupational Safety and Health Administration (OSHA)-required surveillance exams. Other long-standing benefits of the EHRS include increased chart accuracy, reductions in potential medical errors due to direct import of laboratory data via direct interface capability, and the ability to analyze trends in employee health information across the Agency and focus health promotion efforts.

The OCE-led NASA Technical Standards Program developed and published five NASA Engineering Standards and Handbooks, while the use of the Web has resulted in over 112,000 technical standards products downloaded by the Agency. The NASA Engineering and Safety Center accepted 59 requests for independent technical assessment and support activities in FY 2015. Human Systems International (HSI), a division of the Project Management Institute (PMI), recently named Academy of Program/Project and Engineering Leadership (APPEL) the "best academy in the world" in the provision, development, and improvement of project management learning and development. OCE completed the Baseline Technical Capability Assessments for 16 Engineering disciplines and three Systems capabilities.

## WORK IN PROGRESS IN FY 2016

In FY 2016, OSMA will examine NASA's aging layered pressure vessels to better understand the material properties, analysis methodologies, and inspection techniques. The SMA program will conduct safety reviews and independent technical assessments for NASA missions.

OCHMO is continuing to establish health, medical, human performance policies, requirements, and standards for all human space flight programs and projects; technical standards levied on or supported by research and technology programs and projects; and NASA-unique occupational and environmental health requirements that are not mandated by OSHA or the Environmental Protection Agency. In cases where there is no NASA-unique or federally mandated health/medical requirement or standard, OCHMO is also responsible for establishing policies, procedures and standards. In addition to providing direction and oversight for a rapid review of crew health and safety in support of the one-year on-orbit International Space Station mission, OCHMO will lead the Multilateral Medical Policy Board in addressing and resolving several critical issues dealing with crew health and medical operations support to Soyuz landings.

The IV&V Program is currently providing software expertise to 17 projects, including 13 NASA missions, Commercial Crew Program, 3 multi-agency missions, and across 8 NASA Centers. Additionally, the IV&V Program is continuing to enhance its technical capabilities in the areas of cybersecurity and information assurance ensuring that NASA missions are secure.

OCE, including the NASA Engineering and Safety Center (NESC), continues to support the achievement of the Agency's major priorities. Through the Agency technical reviews, OCE maintains Technical Authority caucuses to ensure full integrity and to ensure all dissenting and divergent opinions are fully heard and appropriately considered. The NESC plans to conduct over 50 independent assessments of NASA's highest risk challenges maintaining prioritization on the ISS, Commercial Crew, Orion/SLS, Webb, and Space Technology. OCE continues to be an active participant in the Agency's Technical Capability Assessment Team efforts and provides leadership for a number of discipline-related assessments.

# SAFETY AND MISSION SUCCESS

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

- At the core of the Agency's preventive approach to achieve safety, health, and mission success are:
- Active engagement with NASA programs and institutions to advise, advocate, and ensure safety and mission success;
- Routine on-site inspections and regular self-audits to ensure compliance with mandatory regulations, Agency policies, industry standards, and best practices;
- Robust knowledge management and communities of practice that capture and inculcate lessons learned into future missions;
- Multi-faceted training and development programs to ensure the SMS workforce has the necessary skills and capabilities; and
- Comprehensive review processes to identify and mitigate risks and to analyze and understand failures when they occur. This strategy and practice will continue to provide a systematic approach to support mission success.

OCHMO will continue to implement the HMTA as it pertains to all technical standards for R&T and human space flight programs and projects, as well as those that relate to occupational and/or environmental health requirements that are not established by OSHA or EPA. Additionally, OCHMO will continue to support the only two non-military Aerospace Medicine residencies in the U.S. - Wright State University and the University of Texas Medical Branch - to ensure the sustainability of the discipline, as well as to support the pipeline for future talent.

In FY 2017, IV&V will continue to provide expert software analysis on NASA's safety and mission critical software to help assure safety and mission success by identifying software problems as early as possible, minimizing the cost of rework, and supporting key milestone decisions. Additionally, the IV&V Program will continue to enhance its technical capabilities and focus on continuous improvement and value.

Collaborative efforts between OSMA, OCE, and OCHMO will continue to strengthen the Agency's Technical Authority capability. The offices will continue to work together, conducting safety reviews and independent technical assessments of NASA's missions, including ISS, Commercial Crew, Orion/SLS, Webb, robotic missions, and Space Technology investments.

## Program Elements

### SAFETY AND MISSION ASSURANCE

SMA establishes and maintains an acceptable level of technical excellence and competence in safety, reliability, maintainability, and quality engineering within the Agency. SMA assures that the risk presented by the lack of either safety requirements or compliance with safety requirements is analyzed, assessed, communicated, and used for proper decision-making and risk acceptance by the appropriate organizational leader.

Fundamental to these responsibilities are the definition and execution of a robust and well-understood methodology and process for the application of the safety, reliability, and quality in defining the level of risk. SMA conducts a schedule of reviews and assessments that focus on the life cycle decision milestones for crucial NASA programs and projects as well as for safety, reliability, and quality processes. Embodied in this program is a structured development of methodology and investigation into system attributes that improve the probability of mission success.

The NASA Safety Center is an important component of SMA and is responsible for consolidating Agency-wide SMA efforts in four key areas: SMA technical excellence, knowledge management, audits and assessments, and mishap investigation support.

## OFFICE OF THE CHIEF ENGINEER

OCE establishes and maintains program/project management and engineering policy and technical standards, creating the foundation for excellence of the Agency's program and project management and engineering workforce, system-engineering methodology, and the Agency's system of engineering standards. The office manages the NESC, which is responsible for enabling rapid, cross-Agency response to mission critical engineering, and safety issues at NASA and for improving the state of practice in critical engineering disciplines. Established in FY 2003 in response to the recommendations of the Space Shuttle Columbia Accident Investigation Board, the NESC performs independent testing, analysis, and assessments of NASA's high-risk projects to ensure safety and mission success. SMS funding provides for the core NESC organization of senior engineering experts from across the Agency, including the NASA Technical Fellows and technical discipline teams. As an Agency-wide resource with a reporting path that is independent of the Mission Directorates and independently funded from OCE, the NESC helps ensure safety and objective technical results for NASA.

OCE sponsors the Academy of Program/Project and Engineering Leadership to develop program and project management and systems engineering skills. This academy provides a formal professional development curriculum designed to address four career levels from recent college graduate to executive. The OCE professional development programs directly support project teams in the field through workshops, coaching, interactions with technical experts, training, forums, and publications. The office enables technical collaboration and information sharing through the NASA Engineering Network. The NASA Engineering Network is an Agency-wide capability providing single point access to technical standards, communities of practice, and lessons learned in a secure operating environment. The engineering standards program maintains compliance with Office of Management and Budget Circular A-119 and offers a centralized source of required engineering standards for NASA programs and projects at one-fourth the cost of a decentralized approach.

## OFFICE OF THE CHIEF HEALTH AND MEDICAL OFFICER

OCHMO promulgates Agency health and medical policy, standards, and requirements, to support the medical technical capabilities of the Agency. It assures the physical and mental health and well-being of the NASA workforce, and assures the safe and ethical conduct of NASA-sponsored human and animal research. The office monitors the implementation of health and medical related requirements and standards in all developmental human space flight programs through designated discipline experts at NASA Centers. The office provides oversight of medical and health related activities in operational human space flight through Center-based discipline experts and clinical boards. Annual certified continuing medical education activities and flight surgeon education support ongoing medical and health discipline professionalism and licensure. To maintain clinical currency, OCHMO sponsors university-based physician training programs. NASA's biomedical research programs, in support of human space flight, are guided by NASA-developed health and medical standards.

## INDEPENDENT VERIFICATION AND VALIDATION

Software on NASA's missions is extremely critical. IV&V is a proven means of making sure this critical software works properly. Because IV&Vs can identify software problems as early as possible, it can help minimize the cost of software development and potential rework.

The NASA IV&V Program provides software expertise, services, and resources to improve the likelihood for safety and mission success for NASA's programs, projects, and operations. The IV&V Program analyzes mission software, independently from the developing organization, on NASA's most critical software systems to assure safety and mission success of those systems.

IV&V applies state of the art analytical methods and techniques, complemented with effective software engineering tools and best practices, to evaluate the correctness and quality of critical and complex software systems throughout the project's system development life cycle.

IV&V provides resources and software expertise to other SMA elements in support of independent evaluations of software related approaches and processes. The IV&V Program supports sustaining software technical excellence in the SMA community, sustaining software domain knowledge within the SMA organization, and formulating software development improvement recommendations to the Agency.

IV&V performs independent testing of critical system software to enhance the likelihood of discovering the most difficult kinds of problems in mission software early in the development lifecycle. Critical system software problems can surface because of multiple complex interactions, under specific environmental and operational conditions, and under unique software configurations. The IV&V program's independent test capability enables:

- Advanced testing and simulations of NASA's mission and safety critical software;
- Testing and evaluation of robotics and intelligent systems;
- Capability development within the systems engineering disciplines; and
- Training and education for workforce and students.

# AGENCY IT SERVICES (AITS)

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| IT Management | 14.6 | -- | **20.0** | 17.4 | 18.8 | 20.4 | 25.2 |
| Applications | 62.8 | -- | **58.0** | 59.6 | 61.2 | 62.6 | 63.7 |
| Infrastructure | 98.0 | -- | **166.3** | 172.1 | 155.6 | 157.3 | 156.1 |
| **Total Budget** | **175.5** | -- | **244.3** | **249.1** | **235.6** | **240.3** | **245.0** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**Network Transformation: Agency leadership reconfirmed its commitment to improving the way NASA manages its networks by shifting management of network and communications services from a Center-centric approach to a more efficient enterprise model.**

The AITS program provides secure, effective, and affordable information technologies and services to enable NASA's mission. In alignment with the 2014 NASA Strategic Plan, NASA published the 2014 Information Resources Management Strategic Plan with three Information Resource Management goals and underlying objectives. These goals include providing mission-enabling IT capabilities, risk-based cyber security, and a sustainable management approach to support NASA's diverse mission needs. The AITS program, through the Office of the Chief Information Officer (OCIO), provides effective and efficient IT solutions and innovations to assist NASA's scientists, engineers, and analysts in achieving mission success. The program also improves citizen access to NASA scientific data and increases citizen participation in NASA activities.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

Funding is reallocated within SSMS and from Missions to Agency Information Technology Services to consolidate network transformation, operations, and voice services under the Agency CIO. Through the Mission Backbone Transition activities, the Agency will complete the migration of all mission customers with routed data to the next generation mission network. This will enable opportunities to reinvest operations and maintenance (O&M) cost savings when NASA decommissions the legacy mission network infrastructure. In addition, NASA will deploy the Network Access Control activity adding endpoint interrogation, network zoning, and automatic placement of users and devices in appropriate network zones. The Agency expects to make further use of Voice over Internet Protocol (VoIP) technology.

# AGENCY IT SERVICES (AITS)

To develop critical IT infrastructure and enterprise solutions, $20 million is requested for an IT Investment Fund to modernize Agency systems, increase automation, and optimize delivery of enterprise-wide IT service solutions. Consolidating funding for Agency IT investments in AMO/AITS improves the Agency CIO's ability to comply with the IG Audit and FITARA recommendations by providing visibility and involvement of the Agency CIO in the management and oversight of IT resources across the Agency.

## ACHIEVEMENTS IN FY 2015

### IT MANAGEMENT

NASA conducted a strategic BSA in FY 2015 to evaluate IT services and assess whether NASA's IT program operates effectively and efficiently while meeting requirements. The BSA promotes the understanding and management of IT services in relation to other NASA services and capabilities. Through the BSA, the Agency committed to improving the way NASA manages IT. For example, NASA is transforming the management of network and communications services from Center-centric approaches to an enterprise model that improves efficiency and network security. The Agency further enabled network transformation via the BSA by realigning certain communications funding from individually managed Center budgets to the NASA CIO's budget in the AITS Program effective in FY 2016 to facilitate management of these services using an end-to-end enterprise approach. NASA plans to build from these initial steps in FY 2016 and FY 2017.

NASA is working to implement FITARA and the BSA on IT services is helping with that implementation. The BSA concluded with recommendations that align with the FITARA requirements. Therefore, a significant portion of NASA's FITARA implementation is embedded in the BSA-driven implementation of NASA's new IT governance structure and functional changes. The BSA found that roles including the NASA CIO, Chief Enterprise Architect, and Program Executives required greater authority in order to obtain broader visibility and exercise greater influence over IT investing. FITARA mandates the Agency CIO be held accountable for the effective and efficient management of IT resources across the Agency by granting approval authority over all IT spend, while increasing the CIO's responsibility in IT procurement processes. Further, NASA needed a simpler IT governance structure to implement and oversee the policies that guide these functions. NASA has a series of BSA-driven activities over the next two years that will implement increased IT investment visibility and accountability.

### APPLICATIONS

NASA completed the implementation of the E-Gov Travel Services 2 (ETS2) system. The Electronic Forms Initiative (EFI) transitioned to MSFC for ongoing operations and maintenance and ARC retired the Agency's legacy electronic forms solutions.

### INFRASTRUCTURE

IT Security: NASA met the OMB-mandated goal of 100 percent PIV smartcard use for privileged account access and enabled 76.7 percent (exceeding the OMB goal of 75 percent) PIV use for non-privileged access. NASA completed upgrades for the SOC at ARC. These upgrades spanned 27 Intrusion Detection Systems (IDS) that increased the Agency's readiness to combat cyber threats.

# AGENCY IT SERVICES (AITS)

NASA implemented the first phase of Continuous Diagnostics and Mitigation (CDM) with the Department of Homeland Security (DHS). CDM improves information system security and risk management through continuous control monitoring and ongoing authorization methods. In parallel, the project team developed a plan to implement the Risk Information Security Compliance System (RISCS), which will integrate cybersecurity data sources and provide a risk-based view of NASA's IT systems and operating environments. NASA established the Agency IT Risk Management (AITRM) program to manage these capabilities and oversee execution of the IT security risk management strategy. AITRM marks NASA's shift toward use of a risk-based approach to secure IT services.

Communications: In FY 2015, NASA continued the implementation of an external network border to include enterprise-level firewalls, remote access, web proxy, and content filtering and to implement an internal network environment to include a NAC and zoned architecture solution to authenticate, assess, validate, and place network-connected endpoints and users into the appropriate security zone. NASA improved the management and operations of Agency network systems and services by implementing an enterprise Network Operations Center (NOC) and migrating monitoring and configuration of routers, switches, and firewalls from multiple Center-centric approaches to an enterprise approach.

Computing: In FY 2015, NASA migrated its web services environment into the cloud framework. NASA used an enterprise cloud computing approach to minimize adoption costs, realize volume purchase benefits, and drive consistent security and technical integration with NASA's infrastructure. NASA launched a cloud environment for general-purpose users and an environment for the NASA team that provides business services. NASA has approximately 40 projects in the general-purpose environment, with adopters spanning all NASA Centers and mission areas as well as users with institutional requirements. As of the end of FY 2015, NASA had closed 29 of 59 data centers since the beginning of the data center consolidation effort, resulting in 37,769 square feet of space closed for disposal or repurposing. NASA completed three data center closures in FY 2015.

Web Services: NASA migrated over 15 websites into a Drupal-as-a-Service environment in the public cloud to enable users to publish websites easily and effectively using minimal programming. NASA also transitioned to a free, open source cloud-based search technology that is driving a 50 percent reduction in infrastructure and licensing cost with an estimated one million dollar cost avoidance over the next five years.

End User Services: NASA designed and deployed the first phase of enterprise Mobile Device Management (MDM) during FY 2015 and initiated the enrollment of all NASA devices into the system. This capability provides a single enterprise tool to manage all NASA mobile devices, improving the accuracy of our inventory and the protection of NASA data.

Information Management: In partnership with the National Institutes of Health (NIH), NASA implemented the use of NIH's PubMed Central for NASA's peer-reviewed publications. NASA released over 30,000 datasets and 40 application-programming interfaces (APIs) during FY 2015 through its public online portal at https://data.nasa.gov/, supporting the Federal Cross-Agency Priority Goal to open government data. The government-wide Web site, http://www.data.gov/, lists all datasets available on NASA's data portal.

# AGENCY IT SERVICES (AITS)

## WORK IN PROGRESS IN FY 2016

### IT MANAGEMENT

Information Management: NASA is currently implementing an Agency Data Strategy that includes the data fellows and data stewards programs and the data analytics lab. NASA is complying with the open data and open government mandates to enable high quality digital assets and a data set publication process within NASA, while exploring the Internet of Things to provide opportunities to leverage existing technologies and data trends.

### APPLICATIONS

NASA is upgrading the business systems infrastructure to ensure Agency business systems performance, stability, and efficiency. NASA is completing the Phase-3 Operations Readiness Review (ORR) of the NASA Aircraft Management Information System - Logistic Upgrade (NAMIS-LU). This upgrade is replacing obsolete IT that is no longer supported by the vendor.

### INFRASTRUCTURE

IT Security: NASA is implementing the second phase of the CDM program. CDM provides NASA with the capabilities needed to identify IT security risks on an ongoing basis, prioritize these risks, and enable IT security personnel to mitigate the most significant problems first. CDM also provides IT security tools, Federal and Agency dashboards, integration support, and strategic sourcing. NASA is using an anti-phishing solution to reduce the number of incidents that result from malware infections and acquired licenses to expand anti-phishing exercises Agency-wide to support awareness training. NASA continues to develop the AITRM program, which will integrate technical solutions and data, processes, roles and responsibilities, and reporting essential to mitigating risk, enabling risk-based decision making, and improving NASA's risk posture. NASA is developing an Information Security Continuous Monitoring (ISCM) Concept of Operations to support a risk-based IT security program.

The Identity, Credentials, and Access Management (ICAM) community will increase the number of systems that provide PIV smartcard authentication, including physical access for all users. This includes a collaboration with the ISS users to develop a Federation solution for NASA's partners to allow data sharing. Based on recommendations from the National Academy of Public Administration, NASA is implementing several security and procedural enhancements to the Foreign National Access Program.

Communications: NASA will complete the Consolidated Network Operations System Project, which will standardize network operations processes and procedures across the CSO Corporate Networks into Center operations and processes. This standardization ensures operational efficiencies by using enterprise best practices to consolidate network services and reduce duplication of effort, while improving overall end-to-end visibility of CSO-managed networks.

NASA is currently generating target architectures, gap assessments, and capital improvement plans for enterprise communications services including WAN, LAN, voice, and cable plant systems. The Agency is implementing enterprise processes with accommodation for Center, mission, and location-specific needs. To enhance the Agency's security posture, NASA continues to re-architect the WANs to establish a defensible Agency network perimeter. Enhancements include improved network security with an enterprise approach to perimeter control and maintenance, (e.g., planning Enterprise Firewall and Web

# AGENCY IT SERVICES (AITS)

Content Filter projects), planning to deploy NAC systems inside NASA's networks, and designing an enterprise PIV-enabled remote access system to replace Center Virtual Private Networks (VPNs).

Computing: NASA is launching two additional communities within the Agency's cloud environment in FY 2016. NASA has initiated the enterprise management of Software-as-a-Service (SaaS) providing a framework for secure use of SaaS across the Agency. This improves NASA's overall security posture and helps protect the Agency from data leakage.

Web Services: NASA will provide Recovery-as-a-Service for cost-effective storage that extends disaster recovery and tiered access storage needs. NASA will also provide the ability to achieve disaster recovery requirements and test disaster recovery scenarios in an isolated sandbox environment as well as provide Backup-as-a-Service. NASA will provide Legacy-Web-Site-as-a-Service and migrate 300 web sites into this cloud-based environment, enabling a low-cost cloud service for web sites that are not frequently updated, supporting Data Center Consolidation and Cloud-first while reducing NASA's IT footprint.

End User Services: NASA continues to build out Mobile Device Management capabilities. The Agency will accommodate the enrollment of personal mobile devices that access NASA data and add certificate-based access to encrypted email on iOS and Android devices. NASA is deploying a new Software Refresh Portal solution that will allow NASA employees to leverage a self-service application and software deployment capability, enabling employees to automatically download and install approved software and patches without requiring a desk-side visit from a support technician. NASA will develop an implementation plan to migrate email and calendaring capabilities to a cloud-based infrastructure.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

### IT MANAGEMENT

The FY 2017 budget includes $3.8M of funding for a Digital Service team. This team is responsible for driving the efficiency and effectiveness of the agency's highest-impact digital services. These digital service experts will bring best practices in the disciplines of design, software engineering, and product management to bear on the agency's most important services.

### APPLICATIONS

NASA will complete the activities for the Contract Management Transformation (CMT), which will position the Agency for increased transparency and efficiency by enabling the Agency's ability to meet regulatory reporting and data management requirements. The NEACC will transition the financial Business Warehouse (BW) on High-Performance Analytic Appliance (HANA) Project, which includes a Disaster Recovery Site at the KSC in Florida. At the completion of this transition, NASA will decommission the Business Warehouse Accelerator (BWA). Implemented in 2008, BWA is now reaching end-of-life support and is not on the vendor's current roadmap.

In FY 2017, the Scientific and Technical Information (STI) Program will focus on enhancements to fully automate the Agency's STI review and approval system and extend the process to all NASA Centers, transitioning into an enterprise solution that will replace the existing Center-based approach.

# AGENCY IT SERVICES (AITS)

## INFRASTRUCTURE

IT Security: Implementation of CDM Phase 2 in FY 2017 will be a key cybersecurity priority. NASA will plan, design, develop, implement, and maintain this capability over the upcoming years. NASA will improve its risk management through the development of the AITRM Program, which will provide a more comprehensive understanding of the cyber risks faced by the Agency. The AITRM program will allow NASA to identify IT security risks on an ongoing basis, prioritize risks based on potential impacts, and mitigate the most significant problems first.

Communications: In FY 2017, NASA will continue its network transformation by transitioning to a single NASA enterprise network and use the bandwidth of the CSO backbone for both corporate and mission data. NASA currently operates two entirely separate backbone infrastructures. One backbone infrastructure is for critical spacecraft/science operations and the other is for Agency corporate services. This unified approach enables a more efficient use of available capacity while improving performance with no degradation to mission services. NASA's mission services will begin transitioning to the new communications backbone, allowing for decommission of legacy transport services, resulting in cost avoidances and efficiencies.

The Agency will improve its network security with an enterprise approach to perimeter control and maintenance, including implementation of the Enterprise Firewall and Web Content Filter, deployment of NAC systems inside NASA's networks, and replacement of Center VPNs with an enterprise enabled solution. NASA will realize efficiencies through additional standardization of network and telecommunications architectures, improvements to service deployment and management processes, and the transition to centralized monitoring and management of Center networks from an enterprise NOC.

Computing: In alignment with the CAP goal for Smarter IT Delivery, NASA will continue to support the Administration's mandate of "Cloud First" when making new or life cycle investments. NASA will add two communities to its cloud environment while providing support in its general-purpose environment for individual users and projects. NASA will continue consolidating data centers in FY 2017 in alignment with the Agency's Construction of facilities plans.

Web Services: NASA plans to implement Secure System Development Life Cycle (S-SDLC) across the Web Application development methodology guidance. The OCIO will partner with mission application development teams to expand the use of Cloud Service Providers for mission applications.

End User Services: NASA will deploy the final MDM service that will incorporate a suite of managed mobile applications available to enrolled NASA and personal devices. The Agency will migrate email and calendaring capabilities to a cloud-based infrastructure.

Information Management: NASA plans to increase the OMB-mandated inventory of open datasets from 32,000 in FY 2015 to 75,000 in FY 2017. NASA plans to increase the number of hosted datasets on data.nasa.gov from 16,000 in FY 2015 to 50,000 in FY 2017 while increasing the number of Application Protocol Interfaces (APIs) hosted on api.nasa.gov from 39 in FY 2015 to 55 in FY 2017. By the end of FY 2017, NASA estimates that it will have 10,000 publications for public consumption on PubMed Central.

# AGENCY IT SERVICES (AITS)

### IT INVESTMENTS

IT investment funds enable NASA to implement projects focused on modernizing old Agency systems, improving cybersecurity risk posture, increasing automation, delivering affordable enterprise-wide IT service solutions, strengthening technical capabilities and achieving cost avoidances/savings through strategic investing/divesting. These investments will enable the Agency CIO to comply with IG audit and FITARA recommendations in the management and oversight of IT resources across the Agency. The projects that comprise this request are of the highest enterprise solution priority. During the year, planned projects may change to accommodate changing priorities. Projects include Mission Network/Security Modernization, Corporate Network Obsolescence, and Enterprise Collaboration Tools. The Mission Network/Security Modernization project will reduce carrier costs and improve the implementation of the mission network modernization for the remaining mission data and voice services. The Corporate Network Obsolescence project will allow the OCIO to make strategic risk-based network refresh decisions at the enterprise level while reducing redundancies and inefficiencies. The Enterprise Collaboration Tools project will standardize and establish a collaborative tool suite that addresses institutional and mission requirements, creates a Capital investment wedge to introduce new technology to support end-user services, and improves strategic sourcing initiatives.

## Program Elements

### IT MANAGEMENT

The IT Management project provides Agency-level capabilities for managing IT and meeting internal and external requirements relative to Agency CIO responsibilities. This project includes the budget for the NASA Office of the CIO to meet OMB guidance, Executive Orders, laws, and regulations. The Agency provides funding for the E-Government activities and Federal CIO Council Committees in which NASA participates. The IT Management project also supports digital services to improve interactions with stakeholders who contribute to or support NASA’s scientific and technical research.

### APPLICATIONS

The Applications project provides upgrades and operations for NASA's business and management systems such as the Core Financial System (SAP), Integrated Asset Management System, the Human Capital Information Environment, and the NASA Aircraft Management Information System. The project also includes NASA’s Center for Internal Mobile Applications (CIMA) to create or host mobile applications. The project provides STI services for the Agency and supports the implementation of specific E-Government initiatives across NASA such as E-Government Travel Services 2 (ETS2).

### INFRASTRUCTURE

The IT Infrastructure project provides core infrastructure capabilities across the Agency, including enterprise-wide e-mail, calendaring, directory services, software management, and the corporate network as well as PIV card systems required for identity and credential management for logical access control. The project also provides the NASA public Web portal, data center and cloud computing services, and enterprise licensing management. To protect the Agency’s vast information assets, the IT Infrastructure project provides enterprise cybersecurity capabilities such as the SOC, continuous monitoring, third-party penetration testing, vulnerability scanning, patch management, and other threat detection and prevention services.

## IT INVESTMENTS

IT investment funds enable NASA to implement projects focused on modernizing old Agency systems, improving cybersecurity risk posture, increasing automation, delivering affordable enterprise-wide IT service solutions, strengthening technical capabilities and achieving cost avoidances/savings through strategic investing/divesting. These investments will enable the Agency CIO to comply with IG audit and FITARA recommendations in the management and oversight of IT resources across the Agency. The projects that comprise this request are of the highest enterprise solution priority. During the year, planned projects may change to accommodate changing priorities. Projects include Mission Network/Security Modernization, Corporate Network Obsolescence, Enterprise Unified Communication/Voice over Internet Protocol (VoIP), and Enterprise Collaboration Tools. The Mission Network/Security Modernization project will reduce carrier costs and improve the implementation of the mission network modernization for the remaining mission data and voice services. The Corporate Network Obsolescence project will allow the OCIO to make strategic risk-based network refresh decisions at the enterprise level while reducing redundancies and inefficiencies. The Enterprise Unified Communication/Voice over Internet Protocol (VoIP) project will ensure that a standard, enterprise voice communications architecture is used. The Enterprise Collaboration Tools project will standardize and establish a collaborative tool suite that addresses institutional and mission requirements, creates a Capital investment wedge to introduce new technology to support end-user services, and improves strategic sourcing initiatives.

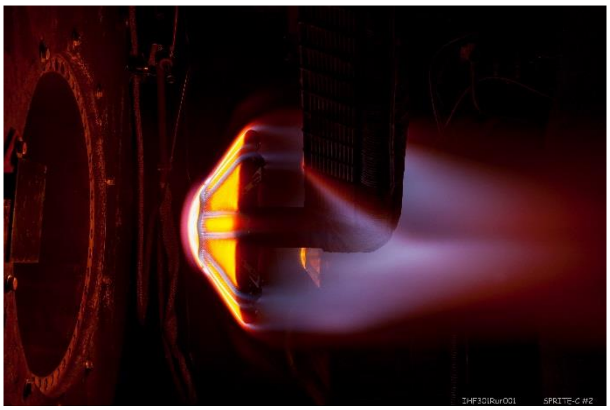
# STRATEGIC CAPABILITIES ASSET PROGRAM

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **26.9** | **--** | **27.0** | **27.5** | **28.3** | **28.9** | **29.5** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**Heating simulation testing of an Adaptive Deployable Entry and Placement Technology model under conditions akin to entering the Martian atmosphere at the Arc Jet Complex, located at NASA's ARC, Moffett Field, California. The Arc Jet Complex is used to simulate the aerothermodynamic heating that a spacecraft endures throughout atmospheric entry. NASA's unique aerothermodynamic testing capability is critical to the design, development, and qualification of spacecraft thermal protection systems (TPS) for space exploration and scientific missions.**

SCAP ensures that select critical test facilities are in a state of readiness. SCAP maintains the skilled workforce and performs essential preventative maintenance to keep these facilities available to meet program requirements. Core capabilities that SCAP supports include: thermal vacuum chambers, simulators, and the Arc Jet Facility.

SCAP manages assets across all Centers, makes recommendations on the disposition of capabilities no longer required, identifies re-investment/re-capitalization requirements within and among classes of assets, and implements changes. SCAP reviews the Agency's assets and capabilities each year to ensure the requirements for the facilities continue to be valid.

SCAP ensures maximum benefit across the Government by broadening its alliances outside the Agency for capabilities (e.g., thermal vacuum chambers). A collaborative working group consisting of the Space Environment Test Alliance Group, including NASA, the Department of Defense (DoD), and other partner entities, facilitates this effort. The group members gain awareness of capabilities across agencies, academia, and industry; share best practices; provide technical support; and refer test programs to facilities best suited to meet test requirements.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None

# STRATEGIC CAPABILITIES ASSET PROGRAM

## ACHIEVEMENTS IN FY 2015

SCAP ensured that the asset capabilities identified as essential by the Agency were maintained in a state of readiness. SCAP maintained the skilled workforce and performed essential preventative maintenance necessary to keep these asset capabilities available to meet current and future program requirements.

The Ames Arc Jet Complex supported testing for Orion, Science Mission Directorate, Space Technology Mission Directorate, and DoD. Testing was also completed for Orion Avcoat architecture down select and CCT Boeing TPS design and launch critical TPS validation of OSIRIS-REx and INSIGHT missions.

SCAP's thermal-vacuum test facility Chamber A supported the completion of the testing for the Webb Optical Ground Support Equipment (OGSE).

The GRC Space Power Facility supported the completion of the checkout and testing of Mechanical Vibration Facility (MVF) table and adapter and Orion backshell acoustic testing.

SCAP's Simulators supported the completion of the modeling and simulation of Interval Management Alternative Clearances (IMACS), Autonomous Aerial Cargo/Utility System development for the Navy, and continued to support the UAS-NAS simulation.

SCAP completed the condition and health assessment for the thermal vacuum capability at MSFC.

## WORK IN PROGRESS IN FY 2016

SCAP's Space Power Facility will prepare and support the Orion Service Module testing, and Orbital Science small fairing testing.

SCAP's thermal-vacuum test facility Chamber A will continue to support Webb and prepare for its Pathfinder test series. SCAP's thermal-vacuum test facility Chamber B will continue to support Z2 space suit testing.

SCAP plans to review and identify high-risk areas for the thermal vacuum capability at Jet Propulsion Laboratory (JPL) to assess the condition and health of the assets.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

SCAP will continue to sustain the strategic technical capabilities needed by NASA to achieve successful missions.

The SCAP program's Space Power Facility will continue to support Orion in thermal vacuum and acoustic testing; SCAP's thermal-vacuum test facility Chamber A will continue to support Webb testing.

SCAP asset capabilities will continue to support the development, testing, verification, and validation for NASA, DoD, NOAA, and Federal Aviation Administration (FAA), in the following areas:

- Simulators: air traffic management technology demonstration, Unmanned Aerial System airworthiness standards and guidelines, motion cueing, loss of control and recovery, enhanced stall modeling and other ongoing development and testing;

- Thermal vacuum and acoustic chambers: Orion, Webb, Mars2020, Commercial Crew and Cargo launch program testing, and other space environmental testing; and
- Arc jet: thermal protection materials, system development, and qualification testing.

## Program Elements

SCAP maintains the skilled workforce and performs the maintenance required to keep essential NASA assets available to meet program requirements.

### SIMULATORS

Simulators are critical components of the success of NASA's aeronautics research in the areas of fundamental aeronautics and aviation safety. These capabilities provide scientists and engineers with tools to explore, define, and resolve issues in both vehicle design and missions operations.

This capability includes an array of research and development crewed flight simulator assets that are in the operations phase and includes:

- A Vertical Motion Simulator and its associated laboratories and equipment located at ARC; and
- A Cockpit Motion Facility and its supporting suite of simulators (the differential maneuvering simulator and the visual motion simulator) and central support facilities for aeronautics and spaceflight vehicle research located at LaRC.

### THERMAL VACUUM, VACUUM, AND ACOUSTIC CHAMBERS

This capability includes several assets located at NASA facilities (GRC, GSFC, JPL, JSC, KSC, and MSFC) that simulate conditions during launch and in space environments. These assets have a minimum outline dimension of 10 feet by 10 feet and can accommodate a complete spacecraft. These chambers have the capability of producing pressures down to 0.01 torr or lower and thermal shrouds capable of liquid nitrogen temperatures (-321 degrees Fahrenheit) or lower. Acoustic chambers are capable of generating approximately 150 decibels at frequencies in the range of 25 to 1,000 Hz.

These chambers are used to perform significant risk mitigation for most NASA payloads launched into space, as well as many payloads in other government agencies, such as NOAA and DoD. Testing performed in these chambers ensures the assembled spacecraft will meet the strict requirements of harsh launch and space environments. Recent successful space vehicles tested in thermal vacuum and acoustic chambers include Magnetospheric Multi-Scale (MMS), Ariane, and SpaceX payload fairing separations.

# STRATEGIC CAPABILITIES ASSET PROGRAM

## ARC JET

This capability includes assets that provide simulated high-temperature, high-velocity environments and support the design, development, test, and evaluation activities of thermal protection materials, vehicle structures, aerothermodynamics, and hypersonic aerodynamics. A gas (typically air) is heated and accelerated to supersonic/hypersonic speeds using a continuous electrical arc. This high-temperature gas passes over a test sample and produces an approximation of the surface temperature and pressure environments experienced by a vehicle on atmospheric entry.

# HEADQUARTERS BUDGET BY OFFICE

## AGENCY MANAGEMENT BUDGET BY HEADQUARTERS OFFICE

| | Actual | Estimate | Request | Notional | | | |
|---|---|---|---|---|---|---|---|
| **($ in millions in full cost)** | **FY 2015** | **FY 2016** | **FY 2017** | **FY 2018** | **FY 2019** | **FY 2020** | **FY 2021** |
| Aeronautics Research | 6.5 | 6.7 | 6.8 | 7.0 | 7.2 | 7.4 | **7.6** |
| Human Exploration and Operations | 25.9 | 26.6 | 28.0 | 28.6 | 29.4 | 30.4 | **31.2** |
| Science | 28.9 | 29.7 | 30.8 | 31.4 | 32.3 | 33.4 | **34.3** |
| Space Technology | 1.3 | 1.4 | 1.4 | 1.4 | 1.5 | 1.5 | **1.6** |
| **Mission Directorates** | **62.6** | **64.4** | **67.0** | **68.4** | **70.4** | **72.7** | **74.7** |
| Office of the Administrator | 8.8 | 7.8 | 8.6 | 8.7 | 8.9 | 9.0 | 9.2 |
| Office of Evaluation | 16.0 | 12.5 | 12.0 | 11.9 | 12.7 | 12.3 | 13.7 |
| Chief Engineer | 3.9 | 4.0 | 4.1 | 4.1 | 4.3 | 4.4 | 4.5 |
| Chief Financial Office | 25.7 | 24.9 | 25.9 | 27.3 | 29.8 | 30.5 | 31.0 |
| Chief Health and Medical Office | 1.8 | 1.8 | 1.8 | 1.9 | 1.9 | 2.0 | 2.1 |
| Chief Information Office | 8.3 | 8.4 | 8.6 | 8.8 | 9.0 | 9.3 | 9.6 |
| Chief Scientist | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.7 | 1.7 |
| Chief Technologist | 4.9 | 5.0 | 5.1 | 5.2 | 5.3 | 5.5 | 5.6 |
| Communications | 13.5 | 14.0 | 14.8 | 15.4 | 15.7 | 16.1 | 16.3 |
| Diversity and Equal Opportunity | 4.1 | 4.1 | 4.6 | 4.7 | 4.7 | 4.9 | 4.9 |
| Education | 3.1 | 2.9 | 3.0 | 3.1 | 3.2 | 3.3 | 3.3 |
| General Counsel | 9.4 | 9.3 | 9.8 | 9.9 | 10.2 | 10.4 | 10.7 |
| International and Interagency Relations | 12.7 | 12.4 | 13.2 | 13.4 | 13.7 | 14.0 | 14.3 |
| Legislative and Intergovernmental Affairs | 3.9 | 4.0 | 4.1 | 4.2 | 4.3 | 4.4 | 4.5 |
| Safety and Mission Assurance | 7.1 | 7.3 | 7.4 | 7.6 | 7.8 | 8.0 | 8.3 |
| Small Business Programs | 1.8 | 1.8 | 1.8 | 1.9 | 1.9 | 2.0 | 2.0 |
| **Staff Offices** | **126.6** | **121.8** | **126.4** | **129.7** | **135.0** | **137.8** | **141.7** |
| NASA Management Office at JPL | 8.0 | 8.0 | 8.0 | 8.1 | 8.2 | 8.4 | 8.5 |
| Human Capital Management | 16.7 | 15.5 | 15.4 | 15.7 | 16.4 | 16.4 | 16.6 |
| Headquarters Operations | 94.8 | 97.9 | 103.2 | 105.0 | 107.5 | 108.9 | 109.8 |

# HEADQUARTERS BUDGET BY OFFICE

| | Actual | Estimate | Request | Notional | | | |
|---|---|---|---|---|---|---|---|
| **($ in millions in full cost)** | **FY 2015** | **FY 2016** | **FY 2017** | **FY 2018** | **FY 2019** | **FY 2020** | **FY 2021** |
| Strategic Infrastructure | 15.1 | 14.7 | 15.7 | 16.0 | 16.3 | 16.6 | **16.9** |
| Procurement | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** |
| Mission Support Directorate Front Office | 10.9 | 11.1 | 11.3 | 11.5 | 11.6 | 11.9 | **12.1** |
| NASA Shared Services Center | 2.9 | 3.2 | 3.4 | 3.4 | 3.5 | 3.6 | **3.7** |
| Protective Services | 7.0 | 6.5 | 6.7 | 6.9 | 7.1 | 7.4 | **7.5** |
| **Mission Support** | 19.1 | 19.5 | 20.5 | 20.4 | 19.8 | 20.0 | **20.2** |
| **Total, Agency Management** | **174.5** | **176.4** | **184.2** | **187.0** | **190.4** | **193.2** | **195.3** |

# HEADQUARTERS TRAVEL BUDGET BY OFFICE

## HEADQUARTERS TRAVEL BUDGET BY OFFICE

| ($ in millions in full cost) | Actual<br>FY 2015 | Estimated<br>FY 2016 | Request<br>FY 2017 |
|---|---|---|---|
| Aeronautics Research* | 0.6 | 0.7 | 0.7 |
| Human Exploration and Operations* | 2.2 | 2.3 | 2.3 |
| Science* | 2.7 | 2.7 | 2.7 |
| Space Technology* | 2.0 | 2.0 | 2.0 |
| **Mission Directorates** | **7.5** | **7.7** | **7.7** |
| Office of the Administrator | 0.8 | 0.9 | 0.9 |
| Office of Evaluation | 0.7 | 0.6 | 0.6 |
| Chief Engineer | 0.5 | 0.7 | 0.7 |
| Chief Financial Office | 0.5 | 0.4 | 0.4 |
| Chief Health and Medical Office | 0.1 | 0.1 | 0.1 |
| Chief Information Office | 0.3 | 0.3 | 0.4 |
| Chief Scientist | 0.1 | 0.2 | 0.2 |
| Chief Technologist | 0.2 | 0.2 | 0.2 |
| Communications | 0.2 | 0.2 | 0.2 |
| Diversity and Equal Opportunity | 0.0 | 0.1 | 0.1 |
| Education* | 0.3 | 0.3 | 0.3 |
| General Counsel | 0.1 | 0.1 | 0.1 |
| International and Interagency Relations | 0.6 | 0.5 | 0.5 |
| Legislative and Intergovernmental Affairs | 0.1 | 0.1 | 0.1 |
| Safety and Mission Assurance | 0.4 | 0.4 | 0.4 |
| Small Business Programs | 0.1 | 0.1 | 0.1 |
| **Staff Offices** | **5.0** | **5.2** | **5.3** |
| NASA Management Office at JPL | 0.2 | 0.1 | 0.1 |
| Human Capital Management | 0.7 | 1.0 | 1.0 |
| Headquarters Operations | 0.1 | 0.1 | 0.1 |
| Strategic Infrastructure | 0.4 | 0.4 | 0.4 |
| Procurement | 0.0 | 0.0 | 0.0 |
| Mission Support Directorate Front Office | 0.5 | 0.2 | 0.2 |

# HEADQUARTERS TRAVEL BUDGET BY OFFICE

| ($ in millions in full cost) | Actual FY 2015 | Estimated FY 2016 | Request FY 2017 |
|---|---|---|---|
| Protective Services | 0.2 | 0.1 | 0.1 |
| **Mission Support** | 0.2 | 0.2 | 0.2 |
| **Total, Agency Management** | **2.3** | **2.1** | **2.1** |

**Travel for the Mission Directorates and Education are funded from their respective appropriation accounts. This chart represents the total travel funding at Headquarters (not just in the SSMS Agency Management program account).*

# HEADQUARTERS WORKFORCE BY OFFICE

## HEADQUARTERS WORKFORCE BY OFFICE

| | Actual | | | | Estimated | | | | Request | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **FY 2015** | | | | **FY 2016** | | | | **FY 2017** | | | |
| | **FTE** | **SES** | **NC*** | **WYE** | **FTE** | **SES** | **NC*** | **WYE** | **FTE** | **SES** | **NC*** | **WYE** |
| Aeronautics Research | 35 | 7 | 0 | 11 | 35 | 7 | 0 | 11 | 35 | 7 | 0 | 11 |
| Human Exploration and Operations | 137 | 18 | 0 | 75 | 137 | 19 | 0 | 75 | 141 | 19 | 0 | 75 |
| Science | 147 | 22 | 1 | 98 | 147 | 24 | 1 | 98 | 149 | 24 | 1 | 98 |
| Space Technology | 7 | 2 | 0 | 11 | 7 | 2 | 0 | 11 | 7 | 2 | 0 | 11 |
| **Mission Directorates** | **326** | **48** | **1** | **195** | **326** | **52** | **1** | **195** | **332** | **52** | **1** | **195** |
| Office of the Administrator | 24 | 4 | 8 | 14 | 24 | 5 | 9 | 14 | 24 | 5 | 9 | 14 |
| Office of Evaluation | 27 | 3 | 1 | 13 | 27 | 3 | 0 | 4 | 27 | 3 | 0 | 4 |
| Chief Engineer | 20 | 7 | 1 | 18 | 20 | 9 | 1 | 18 | 20 | 9 | 1 | 18 |
| Chief Financial Office | 102 | 8 | 2 | 34 | 102 | 10 | 2 | 34 | 102 | 10 | 2 | 34 |
| Chief Health and Medical Office | 10 | 2 | 0 | 1 | 10 | 2 | 0 | 1 | 10 | 2 | 0 | 1 |
| Chief Information Office | 43 | 5 | 0 | 67 | 43 | 5 | 0 | 67 | 43 | 5 | 0 | 67 |
| Chief Scientist | 6 | 1 | 0 | 1 | 6 | 2 | 0 | 1 | 6 | 2 | 0 | 1 |
| Chief Technologist | 26 | 1 | 2 | 3 | 26 | 1 | 2 | 3 | 26 | 1 | 2 | 3 |
| Communications | 51 | 1 | 7 | 27 | 51 | 1 | 7 | 27 | 51 | 1 | 7 | 27 |
| Diversity and Equal Opportunity | 14 | 2 | 0 | 18 | 14 | 3 | 0 | 18 | 16 | 3 | 0 | 18 |
| Education | 17 | 3 | 0 | 1 | 17 | 3 | 0 | 1 | 17 | 3 | 0 | 1 |
| General Counsel | 41 | 5 | 2 | 0 | 41 | 6 | 2 | 0 | 41 | 6 | 2 | 0 |
| International and Interagency Relations | 52 | 8 | 1 | 9 | 52 | 8 | 1 | 9 | 52 | 8 | 1 | 9 |
| Legislative and Intergovernmental Affairs | 27 | 1 | 4 | 1 | 27 | 1 | 4 | 1 | 27 | 1 | 4 | 1 |
| Safety and Mission Assurance | 35 | 11 | 0 | 8 | 35 | 11 | 0 | 8 | 35 | 11 | 0 | 8 |
| Small Business Programs | 5 | 1 | 0 | 4 | 5 | 1 | 0 | 4 | 5 | 1 | 0 | 4 |
| **Staff Offices** | **500** | **63** | **28** | **219** | **500** | **71** | **28** | **210** | **502** | **71** | **28** | **210** |
| NASA Management Office at JPL | 23 | 1 | 1 | 2 | 23 | 1 | 0 | 2 | 23 | 1 | 0 | 2 |
| Human Capital Management | 33 | 5 | 0 | 14 | 33 | 4 | 0 | 14 | 33 | 4 | 0 | 14 |
| Headquarters Operations | 96 | 4 | 0 | 339 | 95 | 4 | 0 | 339 | 97 | 4 | 0 | 339 |
| Strategic Infrastructure | 53 | 4 | 0 | 2 | 53 | 4 | 0 | 2 | 53 | 4 | 0 | 2 |
| Procurement | 32 | 3 | 0 | 0 | 32 | 4 | 0 | 0 | 32 | 4 | 0 | 0 |
| Mission Support Directorate Front Office | 14 | 4 | 0 | 2 | 14 | 5 | 0 | 2 | 14 | 5 | 0 | 2 |
| Protective Services | 46 | 3 | 0 | 8 | 46 | 3 | 0 | 8 | 48 | 3 | 0 | 8 |
| **Mission Support** | 296 | 24 | 1 | 367 | 296 | 25 | | 367 | 300 | 25 | 0 | 367 |

# HEADQUARTERS WORKFORCE BY OFFICE

| | Actual | | | | Estimated | | | | Request | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FY 2015 | | | | FY 2016 | | | | FY 2017 | | | |
| | FTE | SES | NC* | WYE | FTE | SES | NC* | WYE | FTE | SES | NC* | WYE |
| **Total Agency Management** | **835** | **80** | **16** | **802** | **834** | **84** | **14** | **802** | **844** | **84** | **14** | **802** |

**NC is Non-Career*

# CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Construction of Facilities | 374.4 | -- | **328.0** | 297.9 | 303.8 | 310.1 | 317.9 |
| Environmental Compliance and Restoration | 71.7 | -- | **91.8** | 92.3 | 94.2 | 95.9 | 96.2 |
| **Total Budget** | **446.1** | **388.9** | **419.8** | **390.2** | **398.0** | **406.0** | **414.1** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

# CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Construction of Facilities | 374.4 | -- | **328.0** | 297.9 | 303.8 | 310.1 | 317.9 |
| Environmental Compliance and Restoration | 71.7 | -- | **91.8** | 92.3 | 94.2 | 95.9 | 96.2 |
| **Total Budget** | **446.1** | **388.9** | **419.8** | **390.2** | **398.0** | **406.0** | **414.1** |
| Change from FY 2016 | | | **30.9** | | | | |
| Percentage change from FY 2016 | | | **7.9%** | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**Office Building 4220 at MSFC received Leadership in Energy and Environmental Design (LEED) Silver certification in 2015. NASA's inventory of sustainable facilities now exceeds 2.8 million square feet.**

NASA designs and implements its construction of facilities projects, facility demolition projects, and environmental compliance and restoration activities through its Construction and Environmental Compliance and Restoration (CECR) account.

Construction of Facilities (CoF) makes capital repairs and improvements to NASA's infrastructure and provides NASA projects and programs with the test, research, and operational facilities required to accomplish their missions. About 82 percent of NASA's infrastructure and facilities are beyond their constructed design life, thus posing elevated and rising risk to current and future missions. Aging, Apollo-era legacy infrastructure is inefficient and costly to maintain and operate, and assets over 40 years old pose a significant risk to NASA's unique research and development mission. To address these challenges, NASA's CoF program focuses on reducing and modernizing NASA's infrastructure into fewer, more efficient sustainable facilities.

Environmental Compliance and Restoration (ECR) projects clean up pollutants released into the environment during past activities. NASA prioritizes these cleanups to protect human health and the environment, and preserve natural resources for future missions.

Together, these construction and remediation activities help ensure that NASA's assets are ready, available, and appropriately sized to conduct NASA's missions.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

# CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

## ACHIEVEMENTS IN FY 2015

NASA completed significant infrastructure repair projects, including the Repair Electrical Distribution and Control Systems Phase 1 at the Glenn Research Center (GRC), Refurbish North Wing Building 45 at Johnson Space Center (JSC), Rehab Central Steam Facility at the Marshall Space Flight Center (MSFC), Revitalize/Repair of Central Chilled Water Systems also at MSFC, and Upgrade/Repair Critical 16.5 kilovolt (kV) Electrical Distribution System at the Jet Propulsion Laboratory (JPL).

NASA initiated projects to repair and revitalize its aging infrastructure. Significant projects include: Replace Electrical Reliability of Agency Telecom Gateway (Building N254) at the Ames Research Center (ARC), Replace Varnished Cambric Lead Cables also at ARC, Repair by Replacement Human Health and Performance Laboratory at JSC, and Rehabilitate Site-wide High Pressure gaseous helium (GHe), gaseous nitrogen (GN) and Air Distribution Phase 1 at the Stennis Space Center (SSC).

To reduce the Agency's footprint, NASA demolished approximately 100,000 square feet of office and warehouse space.

NASA continued the Energy Savings Investments portion of Institutional CoF by beginning construction of a Chilled Water Thermal Energy Storage System at Kennedy Space Center (KSC). When this project is completed, chilled water production in the industrial area will shift to off-peak electricity rates resulting in reduced energy costs.

Programmatic CoF activities continued to focus on meeting the requirements of the Space Launch System (SLS) program. Projects included restoration of the B-2 test stand at SSC; work in the Vehicle Assembly Building (VAB) and Launch Complex 39-B (LC-39B) at the KSC, and construction on the two structural test stands at MSFC. Additionally, workers at Michoud Assembly Facility (MAF) completed construction to support manufacturing of the SLS core stage.

Within the ECR program:

- Santa Susana Field Laboratory (SSFL) began demolition of buildings not associated with test stands and continued development of work plans for soil cleanup, continued soil, and groundwater cleanup treatability studies, groundwater field investigations, operations of groundwater treatment system and long-term monitoring of groundwater. Cultural resource actions were prepared per the Programmatic Agreement with the State Historic Preservation Office, Native Americans and consulting parties.
- MSFC completed cleanup activities at the former Stauffer Chemical Plant site, a time critical removal for the Industrial Sewer operable unit and an interim remedial action at the Source Area 2 Groundwater site and began design activities for the cleanup of petroleum-contaminated sites at the Center.
- White Sands Test Facility (WSTF) continued to operate the plume front and mid-plume front treatment systems to capture and treat contaminated groundwater. They also continued source area investigations and closure activities of the sewage lagoon.
- KSC installed several new groundwater treatment systems, completed extensive contaminated soil removal at various sites, continued sampling of over 400 monitoring wells, and continued operations of existing groundwater cleanup systems.

- At the JPL, the program continued to operate and maintain systems to clean up contaminated groundwater emanating from JPL, as well as operations and system upgrades to the Lincoln Avenue and Monk Hill drinking water treatment systems.

## WORK IN PROGRESS IN FY 2016

Planned Institutional CoF projects will protect the Agency's critical assets, improve mission assurance, reduce mission risk, and maintain mission essential capabilities. These include utility system repairs and replacement of obsolete buildings. Construction will begin on the Measurement Systems Laboratory to consolidate existing aging laboratories into a smaller efficient and modern research facility. This project will make progress toward correcting deficiencies noted by the National Academies and support core NASA research efforts. Other on-going projects include the Repair by Replacement Building 4221 at MSFC and KSC's Central Campus Phase 1.

Energy Savings Investments projects continue to focus on achieving Federal energy requirements, which result in utility cost avoidance.

Exploration CoF activities in FY 2016 include completing the restoration and initiating activation for the B-2 test stand at SSC, and completing and activating the two structural test stands at MSFC in order to qualify test the liquid oxygen and hydrogen tanks for the SLS Launch Vehicle. Work continues at the VAB and LC 39-B at KSC.

To support Space Operations activities, work will continue on the 21st Century Launch Complex at KSC to upgrade various mechanical and lighting systems as well as initiating a project to replace the roof at the Launch Equipment Shop. Additionally, work will continue on the 34-meter Beam Wave Guide (BWG) antenna systems that support Deep Space Network (DSN) at Canberra, Madrid, and Goldstone.

NASA's ECR program includes cleanup activities at all NASA Centers, with priority given to protecting human health and the environment in balance with Environmental Protection Agency and state regulatory agreements and requirements. This priority is demonstrated at the Santa Susana Field Laboratory where NASA is continuing its investigation of contaminated groundwater, completing treatability studies and preparing plans for remediation of soils, and demolition of facilities in accordance with the State of California consent order.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

Planned construction and environmental activities include:

- Major repair and replacement projects that address some deficiencies noted by the National Academies and support core NASA research efforts.
- Commence construction of the Biosciences Collaborative Facility that will consolidate and modernize existing aging technical facilities at ARC. The new complex will support biological research and development initiatives unique to the Agency in support of Fundamental Space Biology, Astrobiology/Exobiology, and Synthetic Biology.

# CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

- Repairs and upgrades at all Centers to mitigate near-term risk to missions by revitalizing electrical, mechanical, life safety, sanitary sewer and water systems.
- Investments to reduce energy cost and consumption to increase progress toward Federal energy requirements.
- Demolition to help eliminate obsolete facilities.
- Continued cleanup of ground water contamination and investigation of soil contamination at WSTF, to include completion of closure activities, implementation of source area facility investigations, long-term monitoring of groundwater, and continued operation of the plume front and mid-plume ground water treatment systems.
- Continuing investigation and cleanup of groundwater and soil contamination at KSC in accordance with State of Florida requirements. Key activities planned include the installation of new groundwater treatment systems, removal of contaminated soils, investigation of additional sites for potential contamination, continued sampling of over 400 monitoring wells, and continued operations of groundwater cleanup systems.
- Operating and maintaining systems to clean up contaminated groundwater emanating from JPL and continued operations of the Lincoln Avenue and Monk Hill drinking water treatment systems;
- Continuing cleanup of contaminated groundwater and soil removal, operations of groundwater treatment systems, and continued long term monitoring of the groundwater at SSFL in accordance with the consent order with the State of California.
- Continuing cleanup activities and long-term monitoring at ARC, MSFC, and MAF.
- Continuing operations of treatment systems and monitoring at AFRC, GRC, Goddard Space Flight Center (GSFC), LaRC, SSC, and Wallops Flight Facility (WFF).
- 21st Century will initiate a minor project to Replace the Logistics Center Roof at KSC.

# CONSTRUCTION OF FACILITIES

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| Institutional CoF | 276.5 | -- | **290.7** | 297.9 | 303.8 | 310.1 | 317.9 |
| Exploration CoF | 67.9 | -- | **8.8** | 0.0 | 0.0 | 0.0 | 0.0 |
| Space Operations CoF | 19.3 | -- | **28.5** | 0.0 | 0.0 | 0.0 | 0.0 |
| Aeronautics CoF | 9.0 | -- | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| Science CoF | 1.7 | -- | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| **Total Budget** | **374.4** | -- | **328.0** | **297.9** | **303.8** | **310.1** | **317.9** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**The Integrated Engineering Services Building at Langley Research Center received LEED Gold certification in 2015.**

NASA's CoF program includes programmatic and non-programmatic construction projects that reduce facility-related risk to mission success and increase sustainability.

The Institutional CoF program provides for the design and construction of facilities projects that enable NASA's infrastructure to meet mission needs. Utility system repairs and replacements improve the reliability of NASA's systems and reduce operational consumption of energy. Refurbishment or repair- by-replacement projects replace inefficient, deteriorated buildings with efficient high-performance facilities. Demolition projects eliminate facilities that are no longer needed. Together these activities reduce operating costs, reduce the Agency footprint, and develop an energy efficient infrastructure to enable NASA's missions.

Programmatic CoF provides specialized capabilities in testing and development that directly support NASA's current missions. These projects enable NASA to provide critical technical capabilities to manufacture, test, process, or operate hardware for NASA programs.

Minor revitalization and construction projects are those with initial cost estimates between $1 and $10 million. Discrete construction projects refer to those with initial cost estimates of $10 million or greater. Centers accomplish routine day-to-day facility maintenance and repair activities with estimates of $1 million or less within program and Center Management and Operations budgets.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

The FY 2017 request for CoF includes funding transferred from Exploration and Space Operations accounts to achieve SLS, and Space Communications and Navigation (SCaN) requirements. Funding associated with all program designs and out-year programmatic construction activities remains in program accounts.

# INSTITUTIONAL COF

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | 276.5 | -- | 290.7 | 297.9 | 303.8 | 310.1 | 317.9 |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**Projects such as the Reduce Seismic Risk to Unitary Plan Wind Tunnel Make-Up Air System at ARC upgrade aging piping infrastructure with code compliant, safer, more resilient systems.**

NASA's Institutional CoF program includes projects to reduce risk, increase efficiency, and reduce operational costs

CoF projects that repair and/or improve NASA's existing facilities reduce facility-related risks to mission success, property, and personnel. NASA prioritizes these projects using a risk-informed process. Projects to increase efficiency support NASA's core capabilities within a smaller, more efficient footprint. These include replacement of old, obsolete, costly facilities with new, high-performance facilities that consolidate core functions and improve flexibility over the life of the facilities. These replacement facilities are flexible so they can address programmatic requirements, both known and still evolving over the next 40 years.

NASA's demolition program eliminates obsolete, unneeded infrastructure to improve efficiency and eliminate safety and environmental risks.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## ACHIEVEMENTS IN FY 2015

NASA constructs sustainable facilities with cost effective and life-cycle analytic design methods in order to meet current Federal requirements. In FY 2015, NASA constructed or modified six facilities, providing nearly 550,000 square feet of sustainable area. Renovation of the WFF for Engineering, a 55,000 square foot laboratory and office mixed use facility earned the building a Silver rating for Existing Buildings (LEED – EB). NASA received sustainable certifications for five newly constructed facilities (LEED NC). These facilities vary in use including: a space station processing laboratory (KSC, LEED Silver); a 110,000 square feet shipping/receiving warehouse (GSFC, LEED Silver); the app. 90,000 square feet Orbiter Display Facility (KSC, LEED Silver); a 150,000 square feet office building (MSFC, LEED

# INSTITUTIONAL COF

Silver) that replaces aged and inefficient operated buildings, and a 133,000 square feet multi-engineering support facility (LaRC, LEED Gold).

During FY 2015, NASA:

- Completed the demolition of 70 structures at various sites. Demolition of inactive and obsolete facilities eliminates the cost of maintaining old, abandoned facilities in a safe and secure condition. Significant completed demolition projects include:
  - Storage Warehouse totaling 14,000 square feet, ARC;
  - Continued demolition of the Shuttle Mate, Demate Facility support facilities (Phase 2) at Armstrong Flight Research Center (AFRC);
  - Maintenance and Operations North Wing totaling 50,000 square feet, KSC; and
  - Building 1192 Office Complex totaling 31,000 square feet, LaRC.
- Began construction of the following critical projects:
  - Replace Electrical Reliability of Agency Telecom Gateway (Building N254) ARC;
  - Replace Varnished Cambric Lead Cables, ARC;
  - Repair By Replacement Human Health and Performance Laboratory, JSC; and
  - Rehab Site-wide HPG He, GN and Air Distribution, Phase 1, SSC.
- Completed construction of the following essential projects:
  - Repair Electrical Distribution and Control Systems, Phase 1GRC;
  - Refurbish North Wing Building 45, JSC;
  - Rehab Central Steam Facility, MSFC;
  - Revitalize/Repair of Central Chilled Water Systems (4473), MSFC; and
  - Upgrade/Repair Critical 16.5kV Electrical Distribution System, JPL.
- Continued the Energy Savings Investments portion of Institutional CoF by beginning construction of a Chilled Water Thermal Energy Storage System at KSC. When this project is completed, chilled water production in the industrial area will shift to off-peak electricity rates resulting in reduced energy expenditures.

## WORK IN PROGRESS IN FY 2016

Significant work in progress includes award to begin construction of the major recapitalization project, the Measurements Sciences Laboratory, LaRC, and continued construction and outfitting of the Human Health and Performance Laboratory, JSC. These projects will correct deficiencies noted by the National Research Council and support core NASA research efforts. Additionally, there is a major repair for the airfield at GSFC/WFF.

Completed sustainable-rated facilities expected in FY 2016 include KSC 200,000 square foot modified OSB II (LEED EB) and the 100,000 square feet GSFC Flight Projects Building (LEED NC). The completion of these facilities and others currently in construction will allow NASA to exceed 3,000,000 square feet and 50 facilities of energy efficient, environment friendly, sustainable working facilities.

In the Energy Savings Investments, NASA awarded the Central Campus Solar Plant Addition at KSC. When completed, this additional solar photovoltaic system will enable KSC’s Central Campus to operate as a net-zero energy building, reducing energy costs for KSC.

# INSTITUTIONAL COF

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

NASA will complete several infrastructure repair projects, including reliability improvement modifications to Repair Center Heating and Cooling Plant Deteriorated Underground Piping at JSC, Revitalize Waste and Waste Water Systems at KSC, provide Electrical Distribution System Upgrades at LARC, Repair Site-wide Natural Gas at SSC, Repair Steam Distribution at GRC, Replace Substation 115kV High Voltage Cables at ARC, and Reduce Risk Seismic Risk to Various Buildings at ARC.

NASA will initiate several projects to repair and revitalize its aging infrastructure. These include electrical and mechanical projects that support NASA research facilities such as the Biosciences Collaborative Facility at ARC, the Vehicle and Aircraft Ground Equipment Maintenance Facility at AFRC, the Steam Distribution Replacement Phase 1 at MSFC, the Rehabilitate Site-wide High Pressure GHe, GN and Air Distribution Phase 2 at SSC, the Repair Emergency Power System for Mission Control Center (MCC) at JSC, and Compressor Station Upgrades Phase 2 at LaRC.

NASA plans to continue Energy Savings Investments that reduce energy cost and consumption in response to the more stringent Federal energy requirements.

# Institutional Discrete Construction of Facility Projects

Discrete construction of facilities projects have initial cost estimates of $10 million or greater.

## BIOSCIENCES COLLABORATIVE FACILITY

Location: Ames Research Center, Mountain View, CA

FY 2017 Estimate: $47.0 million Total Project FY2017 is $47.0 million

### Scope/Description

The construction of a 38,000 square foot modern science laboratory facility will support biological research to the NASA mission. This new facility will consolidate Center wide laboratories and researchers in Fundamental Space Biology, Astrobiology/Exobiology, and Synthetic Biology to improve collaboration and foster an environment for innovation and breakthrough science and help meet energy efficiency goals. The new Biosciences Collaborative Facility will consist primarily of laboratory and laboratory support spaces. Open plan laboratories will optimize collaboration, flexibility, and efficiency. A small number of conference collaborative rooms and enclosed offices will meet acoustic and security requirements. The majority of the offices will be open cubicles to promote collaboration and interaction among research teams.

### Basis of Need

ARC is the Agency leader in Fundamental Space Biology, Astrobiology/Exobiology, and Synthetic Biology. The foundational research conducted in these areas will respond to the priorities of the National Research Council’s inaugural Decade Survey for Life and Physical Sciences, and will contribute directly to the Agency’s strategic objectives in exploration, science, and technology. This laboratory will replace existing dispersed and deteriorated lab spaces that have numerous health and safety issues. Construction of this facility will reduce Current Replacement Value by thirty per cent and will aggregate scientists, researchers, and technicians from throughout the Center into one facility. The facility will also bring together world-class researchers and will be specifically designed to help them work together to achieve even greater discoveries in the future.

| Other Related Costs | Amount |
|---|---|
| Studies/Design | $4.7M |
| Related Equipment | N/A |
| Activation | N/A |
| Other | N/A |

| Estimated Schedule | Start | Complete |
|---|---|---|
| Design | Feb 2014 | Aug 2015 |
| Construction | Jan 2016 | June 2017 |
| Activation | July 2017 | Nov 2017 |
| Operational | Dec 2017 | Dec 2017 |

## RESEARCH SUPPORT BUILDING

Location: Glenn Research Center, Cleveland, OH

FY 2017 Estimate: $2.0 million; Total Project FY 2017 to FY 2018 is $36.5 million

### Scope/Description

The construction of a 75,000 square foot energy efficient research support building, which is the second major step in the approved GRC Master Plan toward the new campus Center, will allow the consolidation of research offices across the Center into the Glenn Downtown area and to replace the aging Engineering & Supply Building No. 21 and part of the Edward Sharp Employee Center Building No.15. Open plan spaces will optimize collaboration, flexibility, and efficiency. A small number of conference collaborative rooms and enclosed offices will be provided where acoustic and security issues dominate. The majority of the offices will be open cubicles to promote collaboration and interaction among teams. The FY 2017 work provides for demolition and site preparation.

### Basis of Need

The approved GRC Master Plan places a high priority on investing in new, smaller, and more efficient facilities to replace existing high-maintenance and inefficient buildings. This project is an essential step in the sequence of demolition and replacement projects and the GRC Master Plan initiative cannot move forward without it. The original Engineering & Supply Building No. 21, built in 1944 and renovated/expanded in 1968, is inefficient and beyond its useful life. The HVAC system is antiquated, and the indoor air quality is deficient. Mold problems in portions of the building pose health concerns for occupants. The building does not have a fire suppression system.

| Other Related Costs | Amount |
|---|---|
| Studies/Design | $2.96M |
| Activation | N/A |
| Other | N/A |

| Estimated Schedule | Start | Complete |
|---|---|---|
| Design | Jan 2015 | Apr 2017 |
| Construction | Jan 2018 | Sep 2019 |
| Activation | Oct 2019 | Jan 2020 |

# INSTITUTIONAL COF

## REPAIR EMERGENCY POWER SYSTEM FOR MISSION CONTROL CENTER

Location: Johnson Space Center, Houston, TX

FY 2017 Estimate: $15.0 million; Total Project is $15.0 million

### Scope/Description

This project replaces the obsolete and failing back up power generation system in building 48, Mission Control Power Plant. Building 48 emergency power systems provides back up power to the MCC and also to the chillers in building 48 that provides primary cooling to the MCC.

This project will revitalize the Mission Control Power Plant to improve the reliability of the power supplied to this mission critical facility by consolidating, replacing and upgrading the generators, controls, and associated electrical components. It will install two 12,470V 2,500 kW diesel generators to provide sustaining power for both the critical power and the essential but interruptible facility loads such as chillers, lights, air handlers, and elevators. The project repairs, updates or replaces switchgear, electrical equipment, power monitoring, controls, and mechanical equipment (radiator, day tank, fans, louvers, AC units, and sound attenuators); two new 480V 1000kW flywheel based UPS systems with associated switchgear, electrical equipment, power monitoring and controls for critical power support; and, a new control room. This project also includes compartmentalization/fire walls between the equipment to improve the safety and reliability of the overall facility.

### Basis of Need

The Building 48 Emergency Power Plant provides uninterruptible reliable back up power to support the critical functions of the Building 30 MCC. The generators also provide power to Building 48 chillers that provide chill water to the MCC. Un-interruptible power supports equipment needed to operate the International Space Station (ISS) and other major programs that support manned flights. NASA flight controllers and ISS Deputy Program Managers have re-validated the requirement for reliable uninterruptible emergency power to the MCC. The NASA MCC flight controller stated that the ISS is “flown from the ground” and the MCC issues approximately 3,000 commands a month to control the ISS. Any down time to the MCC is an increase in risk to the crew, and if a power outage occurs during complex or critical operations, major program complications arise. The Russian controls also are commanded through the Building 30 MCC. Critical and complex phase periods declared by the ISS program require available back up power to ensure no interruption in power and cooling. Interruptions of these services will result in loss of capability to support on orbit operations such as docking, EVAs and other crucial maneuvers supported by the MCC.

The existing Building 48 emergency power plant has five main issues that affect the overall reliability of the system: 1) Equipment Age: The most critical equipment has reached the end of its service life, and is experiencing increasing failure rates as it ages; 2) Operating Restrictions Due to Environmental Air Quality Regulations on Emissions; 3) System Configuration Contains Single Points of Failure; 4) Lack of Compartmentalization, and; 5) Equipment Voltage: The emergency power system currently operates on two different voltages, 6,900V and 480V making the operation of the system complicated, and the two generator systems cannot back each other up.

| Other Related Costs | Amount |
|---|---|
| Studies/Design | $1.05M |
| Outfitting | N/A |
| Activation | N/A |
| Other | N/A |

| Estimated Schedule | Start | Complete |
|---|---|---|
| Design | Jul 2012 | Feb 2014 |
| Construction | Dec 2017 | Dec 2019 |
| Activation | N/A | N/A |
| | | |

## COMPRESSOR STATION UPGRADES, PHASE 2 OF 4

Location: Langley Research Center, Hampton, VA

FY 2017 Estimate: $12.1 million; Total Project FY 2015 to FY 2024 is $51 million

### Scope/Description

Replacing B1247E Compressor #4 system will improve performance, reliability, operational availability, and maintainability of the Compressor Station. The project will replace the Compressor #4 system, associated foundations, and ancillary air-drying, backpressure control, power, coolant, lubricant, air, vent, and instrumentation systems with a new 8 lb/sec (minimum) compressor system rated at 6,000 psi. The new compressor system and ancillary systems will be designed and sized to operate efficiently and reliably.

### Basis of Need

The B1247E Compressor Station is a critical asset that provides high-pressure air to approximately 25 research facilities (wind tunnels) at the Center. The Compressor Station provides a dependable supply of high-pressure air on a daily basis in sufficient quantity and quality to support research/operations. A significant increase in demand for high-pressure air is expected over the next few years. In 2004, significant repair corrected serious issues with the compressors and their infrastructure. The scope, duration, and expense of this refurbishment expanded as the work progressed and more issues were uncovered. The NASA Safety Center (NSC) performed an independent assessment of the operational reliability of the Compressor Station to determine the merits of continuing to refurbish the existing compressors and infrastructure or immediately begin a repair-by-replacement campaign. The NSC recommended replacing all of the compressors and the respective ancillary support systems since they are well beyond their design life. Based on the NSC recommendation, LaRC is pursuing the cost-effective approach of replacing the compressors and associated ancillary systems. This approach will increase system performance, reliability, operational availability, and maintainability enabling the Center to satisfy researcher high-pressure air demand in support of high-priority Agency programs.

| Other Related Costs | Amount |
|---|---|
| Studies/Design | $1.07M |
| Related Equipment | N/A |
| Activation | $0.1M |
| Other | N/A |

| Estimated Schedule | Start | Complete |
|---|---|---|
| Preliminary Engineering Report | N/A | N/A |
| Design | Mar 2015 | Aug 2016 |
| Construction | Mar 2017 | Jun.2018 |
| Activation | Jun 2018 | Dec 2018 |

## REPLACE/REVITALIZE FIRE PROTECTION AND ALARM NODE SYSTEM

Location: Marshall Space Flight Center

FY 2017 Estimate: $15 million; Total project cost is $15 million

### Scope/Description

Replace/Revitalize the failing MSFC emergency reporting and notification infrastructure (node system) to bring the system into compliance with current NASA and industry standards. This work includes repair or replacement of Center-wide facility safety systems and components in electrical, mechanical, civil/structural, and architectural disciplines as required.

### Basis of Need

Much of the propulsion work done throughout MSFC involves highly flammable liquids and gases including hypergolic fluids and propellant mixtures (flammable and oxidizer). These, and similar substances, create an environment that has a greater incident of fire ignition than a typical manufacturing environment. The energy requirement for ignition in many of these environments is a static spark. MSFC has had multiple fire incidents in or near these lab or critical asset areas in the last two years. Research and Development with propellant and other hazardous materials results in a higher-than-normal incident rate. MSFC recently replaced a large number signaling panels, but continues to struggle with the infrastructure tying these assets together.

The nodal system has a sufficient number of constant faults to make the reporting system unreliable for transmission of alarms and off-normal conditions. These conditions must be centrally monitored and maintained to establish a reliable and robust fire protection system and meet NASA STD 8719.11 and NFPA 72 requirements

# INSTITUTIONAL COF

| Other Related Costs | Amount |
|---|---|
| Studies/Design | $900K |
| Related Equipment | N/A |
| Activation | N/A |
| Other | N/A |

| Estimated Schedule | Start | Complete |
|---|---|---|
| Preliminary Engineering Report | N/A | N/A |
| Design | Sep 24, 2015 | Sep 24, 2016 |
| Construction | Jan 15, 2017 | Jul 15, 2018 |
| | | |

## REVITALIZE BUILDING 4708 ELECTRICAL SYSTEM

Location: Marshall Space Flight Center

FY 2017 Estimate: $10.3 million; Total Project cost is $10.3 million

### Scope/Description

Building 4708 (Engineering & Development Laboratory) continues its legacy as one of MSFC's critical facilities. Revitalization of electrical building distribution systems in Building 4708 is required to reduce the risk of building power loss. Additional benefits of this project will be to improve the building safety and energy of a 57-year-old building. Electrical system revitalization shall include but not be limited to the replacement, removal, and modification of building electrical substations, bus ducts, panels, transformers, motor control centers, switchgear, starters, fire alarm systems, detection systems, and control boxes. These modifications will also resize electrical service demand to appropriate levels (considering the new insulated roof and siding) and thereby conserve energy. This work will focus on electrical systems with support work in mechanical, structural, and architectural disciplines as required. This project will be planned, designed, and constructed incorporating sustainable design principles to reduce life-cycle costs, implement pollution prevention, minimize impact on natural resources, and maximize occupant health, safety, and productivity to the maximum extent possible.

### Basis of Need

Obsolete switchboards, buss systems, and panel boards installed in 1958 supply the majority of the electrical power to the Building 4708 multi-program support equipment. . In most cases, direct replacement parts are no longer available or are difficult to acquire and have long lead times of 8 to 12 weeks. While it is feasible to provide a work around for individual component failure, these measures are temporary in nature, violate UL listing and present safety hazards, which must be mitigated during their use. Two 2000 amp, 480 volt service entrance buss systems have failed in the past three years in building 4708 and identical systems have failed in other buildings at MSFC in the past year, e.g., building 4619. A systematic approach to replace the electrical system is necessary to ensure there are no impacts to multiple projects supported in this mission critical facility. The most recent facility condition assessment identified that most system components high on the priority list have an average facility age of 50+ years old with over 74 percent rated in the Poor or Replace condition. The assessment also identified 151 lighting and receptacle panel boards that are in Poor or Replace condition. The Facilities Deferred Maintenance report issued in FY 2011 indicates a need to replace or upgrade aged and degraded electrical equipment to meet code requirements, to provide reliable services, and to ensure life safety conditions.

The facilities within this building support programs such as Advanced Exploration Systems, Orion, SLS, and Chandra X-Ray Observatory along with programs with private partnerships, universities, industry, and other NASA Centers. This facility serves the Center in many ways: supporting multiple functions or missions, proving for large number of personnel, ensuring continued functionality of the Center or a special one-of-a-kind need.

This project will also contribute toward MSFC's requirements to operate at or below the established 2010 energy-efficiency goals and to upgrade aged systems that are safety issues. Continuous use of the facilities in this on-going project, in their current functions, is consistent with the MSFC Master Plan and established energy-efficiency goals and design standards.

| Other Related Costs | Amount |
|---|---|
| Studies/Design | $930K |
| Related Equipment | N/A |
| Activation | N/A |
| Other | N/A |

| Estimated Schedule | Start | Complete |
|---|---|---|
| Preliminary Engineering Report | N/A | N/A |
| Design | Jan 15, 2015 | Aug 30, 2016 |
| Construction | Jan 15, 2017 | Jan 15, 2019 |
| | | |

## REHABILITATE SITE-WIDE HIGH PRESSURE GAS, HE, GN, AND AIR DISTRIBUTION, PHASE 2 OF 2

Location: Stennis Space Center

FY 2017 Estimate: $12.0 million; Total Project FY 2015 to FY 2017 is $22.0 million

### Scope/Description

This project will replace and refurbish the High Pressure Gas Piping system conveying GN, GHe, and high-pressure air (HPA), to the various end user locations on site in order to address aging infrastructure, increased maintenance costs, and operational issues. This project will address the replacement and refurbishment of GN, GHe, and HPA piping on the test complex side of SSC and includes all associated piping, valves, instrumentation, controls, and ancillary materials required to safely distribute high pressure GN, GHe, and HPA to test stands and facilities site-wide. This phased project will extend the life of the site-wide gaseous distribution system and provide NASA and SSC's test stands the capability to support rocket propulsion testing programs. All environmental aspects were addressed and a NEPA Record of Environmental Consideration has been issued.

### Basis of Need

The existing site-wide underground piping system distributing GN, GHe, and HPA is rapidly approaching the end of its useful life as evidenced by the numerous outages over the past several years to repair leaks within the system. External corrosion is the main cause of the degradation of the piping and components in the High Pressure Gas system. One of the main sources of external corrosion is the valve pits for the underground piping system. These valve pits fill up with water and accelerate the external corrosion process on pipe and components in that valve pit. By bringing all piping above ground on the test complex side, we are eliminating the need for valve pits. The capability to distribute high pressure GN, GHe, and HPA across the site is critical to support rocket propulsion testing at SSC. Therefore, it is imperative that we replace and refurbish the site-wide High Pressure Gas System at SSC.

| Other Related Costs | Amount |
|---|---|
| Studies/Design | N/A |
| Related Equipment | N/A |
| Activation | N/A |
| Other | N/A |

| Estimated Schedule | Start | Complete |
|---|---|---|
| Preliminary Engineering Report | N/A | N/A |
| Design | Jul 31, 2015 | Jul 31, 2016 |
| Construction | Jan 15, 2017 | Jul 15, 2019 |
| | | |

## STEAM DISTRIBUTION REPLACEMENT, PHASE 1 OF 2

Location: Marshall Space Flight Center

FY 2017 Estimate: $16.2 million; Total Project FY 2017 to FY 2018 is $32.5 million

### Scope/Description

This project will convert buildings from steam heat to a more efficient and maintainable systems including natural gas, electricity, biomass, solar thermal, solar electrical, and combinations thereof.

### Basis of Need

MSFC presently receives steam to heat the Center’s North Campus, which includes buildings and facilities north of Fowler Road MSFC is currently metered at the MSFC boundary and not at the individual buildings. At the steam delivery pressure the steam is approximately 400 degrees Fahrenheit, which leads to great line losses and thermodynamic inefficiencies. The most cost efficient way to upgrade the system is to replace the steam heat with other forms of heat, electric, natural gas, solar thermal, solar electrical or combinations thereof. This will eliminate distribution inefficiencies of the steam lines and reduce operating and maintenance costs.

| Other Related Costs | Amount |
|---|---|
| Studies/Design | $1.18M |
| Related Equipment | N/A |
| Activation | N/A |
| Other | N/A |

| Estimated Schedule | Start | Complete |
|---|---|---|
| Preliminary Engineering Report | N/A | N/A |
| Design | Jul 15, 2014 | Jul 31, 2015 |
| Construction | Jan 30, 2017 | Jun 30, 2018 |
| | | |

## Minor Revitalization and Construction of Facilities

Minor revitalization and construction of facilities projects have initial cost estimates between $1 million and $10 million. These projects revitalize and construct facilities at NASA facility installations and government-owned industrial plants. Revitalization and modernization projects provide for the repair, modernization, and/or upgrade of facilities and collateral equipment. Repair projects restore facilities and components to a condition equivalent to the originally intended and designed capability. Repair and modernization work includes the equivalent replacement of utility systems and collateral equipment necessitated by incipient or actual breakdown. Modernization and upgrade projects include restoration of current functional capability and enhancement of the condition of a facility so that it can more effectively accomplish its designated purpose, increase its functional capability, or meet new building, fire, and accessibility codes.

The minor revitalization and construction projects that comprise this request are of the highest priority, based on relative urgency, and expected return on investment. The focus is on projects that reduce building square footage or eliminate excess building systems, provide long-term savings, and reduce the Agency's maintenance backlog. During the year, planned projects may change to accommodate changing priorities.

### MINOR REVITALIZATION AND CONSTRUCTION OF FACILITIES BY CENTER, $100.3 MILLION

**Ames Research Center, $18.5 million**
- Replace Arc Jet Diffusers
- Reduce Seismic Risk to Buildings N226, N240, N244, and N245
- Replace Substation 115kV High Voltage Cables

**Armstrong Flight Research Center, $18.1 million**
- Revitalize Industrial/Potable Water Distribution System
- Repair by Replacement, Vehicle & Aircraft Ground Equipment Maintenance Facility

**Glenn Research Center, $9.0 million**
- GRC Repair Steam Distribution, Phase 3

**Goddard Space Flight Center, $2.8 million**
- Replace WFF South Island Electrical Infrastructure

**Jet Propulsion Laboratory, $5.0 million**

- Continue LN2 Storage and Distribution Upgrade

**Johnson Space Center, $12.5 million**

- Repair Central Heating and Cooling Plant Deteriorated Underground Piping (B24) JSC
- Repair Sanitary Sewer System, JSC

**Kennedy Space Center, $11.6 million**

- Revitalize Water & Waste Water Systems, Various Locations, Phase 5 of 6
- Revitalize Water and Waste Water Systems, Phase 6 of 6

**Langley Research Center, $11.8 million**

- B1293 Electrical Upgrades
- Electrical Distribution System Upgrades, Part 1 of 6
- Electrical Distribution System Upgrades, Part 2 of 6

**Stennis Space Center, $11.0 million**

- Refurbish HPA Dryer System
- Rehabilitate/Repair Site-wide Natural Gas System

## Energy Savings Investments

These important projects are focused on improving systems efficiencies and reducing utility costs. The projects that comprise this request are of the highest priority based on expected return on investment or contribution to Federal energy mandates. The group of projects listed below include the simple payback period – the amount of time it will take to recover the initial investment in energy savings. During the year, planned projects may change to accommodate changing priorities.

### ENERGY SAVINGS INVESTMENTS PROJECTS BY CENTER, $12.2 MILLION

**Glenn Research Center**

- Expand Energy Monitoring and Control System, Various Buildings; 6.9 year simple payback

**Jet Propulsion Laboratory**

- Install Solar Photovoltaic System on Parking Structure; 21.3 year simple payback

**Johnson Space Center**

- Implement Energy Conservation Measures and Retro-Commissioning, Various Buildings; 7.2 year simple payback
- Replace Window Walls, Mall Area Buildings; 10.2 year simple payback

## Demolition of Facilities

FY 2017 Estimate: $14.7 million

NASA continues to meet its national fiduciary responsibilities, fully leveraging Agency retained assets to increase their functionality in support of mission success while disposing of unneeded federal real estate-increasing the use of under-utilized assets, minimizing operating costs, and improving energy efficiency.

NASA will use the requested funding to eliminate inactive and obsolete facilities that are no longer required for NASA's Mission. Abandoned facilities pose potential safety and environmental liabilities and are eyesores at the Centers. The Agency must maintain these facilities at minimal levels to prevent increasing safety and environmental hazards, and these recurring maintenance costs impose a drain on the maintenance dollars available at the Centers. Demolishing these abandoned facilities allows the Agency to avoid non-productive operating costs required to keep abandoned facilities safe and secure. Furthermore, demolition is the most cost-effective way to reduce the Agency deferred maintenance.

NASA identifies facilities for the demolition program through special studies to determine if the facility is required for current or future missions. Facilities that are no longer needed are included in a five-year demolition plan that sets project schedules based on last need, annual costs avoided, potential liability, and project execution factors.

## Facility Planning and Design

FY 2017 Estimate: $33.8 million

Facility planning and design funds provide for advance planning and design activities, special engineering studies, facility engineering research, preliminary engineering efforts required to initiate design-build projects, preparation of final designs, construction plans, specifications, and associated cost estimates associated with non-programmatic construction projects. This includes master planning, value engineering studies, design and construction management studies, facility operation and maintenance studies, facilities utilization analyses, engineering support for facilities management systems, and capital leveraging research activities. Funding also supports participation in facilities-related professional engineering associations and organizations.

The facilities planning and design activity is crucial to the implementation of NASA recapitalization strategy. These projects are necessary to make progress toward required sustainability, energy, and stewardship goals.

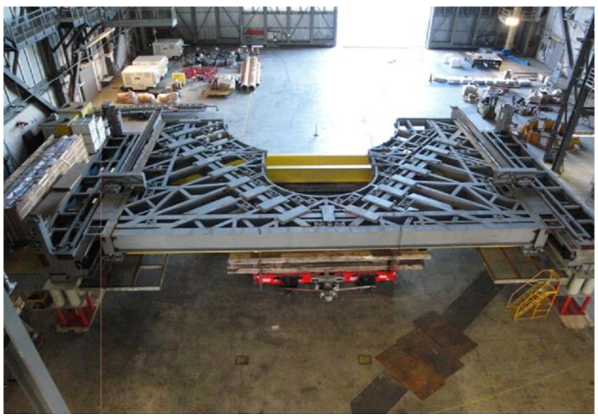
# EXPLORATION COF

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **67.9** | **--** | **8.8** | **0.0** | **0.0** | **0.0** | **0.0** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*



**Platform K in the KSC VAB High Bay 4 being prepared for final fabrication prior to installation in High Bay-3.**

Exploration CoF provides construction required to support SLS, Orion, and Exploration Grounds Systems program activities. Funds required for the planning and design of out-year programmatic construction remain in the applicable program accounts.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## ACHIEVEMENTS IN FY 2015

During FY 2015, NASA continued transitioning from the Space Shuttle and Constellation programs to Exploration. At KSC, construction continued in the VAB and at LC-39B. In the VAB, construction continued on building the access platforms in High Bay 3 to support SLS launch vehicle integration. Both halves of platform K were delivered to the VAB, load tested and prepared for final build-up and installation. At LC-39B, major construction efforts continued on the environmental control systems to support the SLS launch vehicle and Orion, as well as the major undertaking of replacing the Space Shuttle main flame deflector with a shingled steel plate flame deflector for the SLS launch vehicle and other potential users.

The SLS Program continued progress on the build-out of the B-2 test stand at SSC in preparation for the SLS Green Run core stage testing. Work packages 1, and 2 were completed and contractually closed out finishing all restoration aspects of the SLS Green Run Project.

At the MAF, modifications continued to transition from legacy tooling and manufacturing of the Space Shuttle External Tank to tooling and manufacturing necessary for the SLS core stage. Modifications were completed to Building 131 to support thermal protections system application, as well as the cleaning and priming of the liquid oxygen and liquid hydrogen tanks. Modifications were also completed to Building 451 to support the liquid hydrogen tank proof testing and to Building 110 (Cells B & C) to support the vertical welding of core stage elements and (Cells E & F) for cleaning the core stage tank. Repairs to the Building 103 Apron were initiated and completed, as were the modifications to Saturn Boulevard at the Levee Crossing and Barge Dock Repairs to support SLS transportation.

# EXPLORATION COF

At MSFC, construction of the two structural test stands to support SLS core stage qualification testing continued with the foundations complete, cranes on-site, and the vertical erection of steel in progress. On Test Stand 4693 being constructed to test the core stage Liquid Hydrogen (LH2) tank, several key accomplishments were completed, to include the completion of the foundation with structural rebar and anchor rods as well as the vertical erection of four tiers on both twin steel towers. Electrical and fluid lines have been worked and ready for final finish once erection is complete. On Test Stand 4697 being constructed for the core stage Liquid Oxygen (LOX) tank, accomplishments include completing the foundation with structural rebar and anchor threaded holes and rods in preparation for vertical steel erection.

## WORK IN PROGRESS IN FY 2016

Exploration construction activities in FY 2016 support the three programs within the Exploration Systems Division. At KSC, the main effort continues to be the fabrication and installation of the platforms in High Bay 3 of the VAB and the installation of the main flame detector and restoration of the flame trench wall and floor at LC-39B. Other work at LC-39B includes continuing the modifications to the environmental control system, as well as completing the third phase of the water system upgrades and the installation of the ignition over pressure and sound suppression post-liftoff bypass valves. The Orion program is also commencing the third, and final, phase project at KSC to modify the Launch Abort System Facility to support launch abort system integration to the Orion crew module.

Construction of Test Stand 4693 continues with the Tier 5 up to Tier 7 (21 floors), elevators, electrical site utilities, Liquid Nitrogen (LN2) piping installation, crosshead construction/install and final finishes. Construction of Test Stand 4697 also continues with the start of pre-assembly and vertical steel erection of the three Tiers, elevators installation and final utility finishes. Both Test Stands will finish up with the test and checkout of test stands systems and equipment along with inspections and final corrections. Test Stand 4697 is projected to be completed in mid-July of 2016 followed by Test Stand 4693 completion with cross-head installation by the end of FY 2016.

The B-2 Test Stand Work Package 5 was awarded in early FY 2016. Work package 5 is the last major procurement, and includes umbilical support structures, installation of the activation spools, installation of the Environmental Control Systems and the final electrical boxes and connections for the SLS core stage systems. The Tarmac, Work Package 3, Work Package 4, Work Package 5, Electrical Build-out, Tubing installation, and the High Pressure Supplemental Pump work will all be completed prior to the end of FY 2016; thus, completing construction activities of the B-2 Test Stand. The program will begin activating all the major systems this year in preparation of the SLS Green Run Testing. All construction activities on the High Pressure Industrial Water at SSC will be completed by the end of the first quarter of FY 2016.

At MAF, work will continue on modifications to Building 103, Building 110, Building 131, and Building 451 to support SLS Core Stage manufacturing. Modifications also continue in Building 103 to support the Final Integration of the SLS Core Stage. Replacement of the Building 103 sanitary piping will be accomplished, as will the work in Building 103 for final Integration on the Helium System and air handling unit modifications. Work will commence on repairing and replacing the chilled water systems, refurbishing the 50 PSI steam distribution piping, replacing Chiller #3 and Chiller #6, installing containment liners, phase I of replacing Purlins Phase I, and refurbishment of Substations 20A, 43, 63, and 64.

# EXPLORATION COF

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

In FY 2017, Exploration construction will consist of three minor projects. One will replace the roof of the Turn Basin Wharf Modifications at KSC and the other two are at MAF for the second phase of replacing the Roof Purlins Building 103 and the replacement of Substation 1.

## Minor Revitalization and Construction of Facilities

Construction projects with initial cost estimates between $1 million and $10 million are included as minor revitalization and construction projects. These projects provide for the repair, modernization, or upgrade of facilities and collateral equipment required by Exploration activities. Repair projects restore facilities and components to a condition substantially equivalent to the originally intended and designed capability. Repair and modernization work includes the substantially equivalent replacement of utility systems and collateral equipment necessitated by incipient or actual breakdown. Modernization and upgrade projects include both restoration of current functional capability and enhancement of the condition of a facility, so that it can more effectively serve its designated purpose, increase its functional capability, or meet new building, fire, and accessibility codes.

### MINOR REVITALIZATION AND CONSTRUCTION PROJECTS BY CENTER, $8.8 MILLION

**Marshall Space Flight Center, $5.8 million**

- Replace Roof Purlins, Building 103, Phase 2 MAF
- Replace Substation 1, MAF

**Kennedy Space Center, $3.0 million**

- Turn Basin Wharf Modifications, Phase 2

# SPACE OPERATIONS COF

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **19.3** | **--** | **28.5** | **0.0** | **0.0** | **0.0** | **0.0** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*

**The main reflector lift for Deep Space Station (DSS)-36 at Canberra Deep Space Communications Complex, readies NASA for deep space communications operations for the next decade.**

Space Operations CoF provides construction to support Space Communication and Navigation (SCaN), 21st Century Launch Complex, the ISS program and Launch Services Program (LSP). Funds required for the planning and design of out-year programmatic construction remain in the applicable program accounts.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## ACHIEVEMENTS IN FY 2015

Significant work commenced on the Deep Space Network (DSN) DSS-36 34-meter antenna in Canberra Australia with the completion of the pedestal, structural assembly, and the execution of the critical lift for integrating the main reflector structure onto the supporting alidade structure. Facilities work inside of the antenna pedestal, such as HVAC and fire suppression were nearing completion.

Construction was well underway for three 21st Century Launch Complex projects at the WFF, the modifications and repairs to building X-75, relocation of Pad 1, and replacement of the island primary electrical feeder.

## WORK IN PROGRESS IN FY 2016

The SCaN discrete project to construct DSS-36, a 34-meter antenna in Canberra Australia will continue, with expected completion and commissioning of the antenna at the end of FY 2016.

SCaN will also begin construction of a multi-year funded discrete project to construct two new 34-meter BWG DSS Antennas, DSS-56 and DSS-53, at the Madrid Deep Space Communications Complex (MDSCC). During FY 2016, the construction phase will begin with the start of site work in Madrid. Activity for FY 2016 will include the completion of the excavation efforts for both antenna locations.

# SPACE OPERATIONS COF

Additionally, construction and fabrication of the DSS-56 antenna pedestal and structure should be well underway.

All three 21 Century Launch Complex projects at WFF, modifications and repairs to building X-75, relocation of Pad 1, and replacement of the island primary electrical feeder will be completed prior to the end of FY 2016. Additionally, 21st Century Launch Complex is replacing the roof on the on the launch equipment shop at KSC.

The ISS program commenced a project to replace the roof of the SSPF building at KSC.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

SCaN will continue its efforts for the construction of a multi-year funded discrete project to construct two new 34 meter BWG DSS Antennas MDSCC in Spain. In FY 2017, the first antenna pedestal at DSS-56 will be completed. Steel fabrication of the antenna structure will also be completed and delivered to the site by the selected vendor(s). On-site assembly will commence and continue throughout 2017. Additionally, the DSS-53 antenna pedestal work will commence and progress throughout FY 2017. Four projects totaling $5.5M dollars will be initiated in FY 2017 for LSP, SCAN and 21st Century.

# Space Operations Discrete Construction of Facility Projects

Discrete construction of facilities projects have initial cost estimates of $10 million or greater.

## CONSTRUCTION OF 34 METER BEAM WAVE GUIDE ANTENNAS - MADRID

Location: Madrid Deep Space Communications Complex, Madrid, Spain.

FY 2017 Construction Estimate: $23.0 million; Total Project FY 2015 to FY 2019 is $57.75 million.

### Scope/Description

This project constructs two new 34-meter BWG antennas at the MDSCC, provides for the construction of DSS-56 and DSS-53. The project is divided into three contracts: excavation and roads, site infrastructure, and antenna related facilities. The funding for fiscal year 2017 is $23.0 million of the total $57.75 million. The project includes the fabrication and installation of the antenna structures, panels, gearboxes, bearings, electric drives, encoders, BWG mirrors, sub-reflectors and positioners, and related servomotors. The project also includes the construction of the pedestals, as well as all facilities in and around the antennas, including the paved access roads, trenches, drainage, flood control devices, water main and distribution system, antenna apron, perimeter security fence, HVAC systems, electrical power distribution, fire detection and suppression system, and surveillance system assembly.

# SPACE OPERATIONS COF

### Basis of Need

The construction of the 34-meter BWG antennas at Madrid was planned as Phase 2 of the SCaN DSN Aperture Enhancement Project (DAEP) and originally scheduled to begin after completion of the third 34-meter BWG antenna at Canberra. However, the two existing antennas at Madrid, DSS-63 70-meter and DSS-54 34-meter, were showing considerable concrete degradation in their pedestals. Thus, NASA decided to begin construction of the two 34-meter BWG antennas at Madrid in FY 2015 to mitigate future long-term maintenance downtimes of the existing 70-meter and 34-meter antennas.

| Other Related Costs | Amount |
|---|---|
| Studies/Design | $0.5M |
| Related Equipment | N/A |
| Activation | N/A |
| Other | N/A |
| | |

| Estimated Schedule | Start | Complete |
|---|---|---|
| Design | Oct 2013 | Sep 2014 |
| Construction, DSS-56 | Dec 2015 | Oct 2018 |
| Activation, DSS-56 | Dec 2017 | Oct. 2019 |
| Construction, DSS-53 | Sep 2017 | Dec 2020 |
| Activation, DSS-53 | Dec 2019 | Dec 2021 |

## Minor Revitalization and Construction of Facilities

Construction projects with initial cost estimates between $1 million and $10 million are included as minor revitalization and construction projects. These projects provide for the repair, modernization, or upgrade of facilities and collateral equipment required by Space Operations activities. Repair projects restore facilities and components to a condition substantially equivalent to the originally intended and designed capability. Repair and modernization work includes the substantially equivalent replacement of utility systems and collateral equipment necessitated by incipient or actual breakdown. Modernization and upgrade projects include both restoration of current functional capability and enhancement of the condition of a facility, so that it can more effectively serve its designated purpose, increase its functional capability, or so that it can meet new building, fire, and accessibility codes.

### MINOR REVITALIZATION AND CONSTRUCTION PROJECTS BY CENTER, $5.5 MILLION

**Jet Propulsion Laboratory, $1.0 million**
- DSS63 Apron and Subsurface Remediation, Madrid

**Kennedy Space Center, $4.5 million**
- Logistics Facility Roof Replacement
- Building 836/839/840 Parking Repair and Lighting, Vandenberg Air Force Base

# ENVIRONMENTAL COMPLIANCE AND RESTORATION

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | 71.7 | -- | 91.8 | 92.3 | 94.2 | 95.9 | 96.2 |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016. FY 2016 funding levels are subject to change pending finalization of the FY 2016 Operating Plan.*


**Removal of soil contaminated with PCBs, PAHs, and dieldrin at MSFC, Building 4241. In this area, up to 2 feet of surface soil was removed and disposed. Completed in August 2015.**

NASA's ECR program cleans up hazardous materials and wastes that have been released to the surface or groundwater at NASA installations, NASA-owned industrial plants supporting NASA activities, current or former sites where NASA operations have contributed to environmental problems, and other sites where the Agency is legally obligated to address hazardous pollutants. ECR program activities include projects, studies, assessments, investigations, sampling, plans, designs, construction, related engineering, program support, monitoring, and regulatory Agency oversight. Funding also covers land acquisitions necessary to ensure operation of remedial treatment processes and sites as part of remediation and cleanup measures.

For additional information concerning NASA's ECR program, go to: http://www.nasa.gov/offices/emd/home/ecr.html.

## EXPLANATION OF MAJOR CHANGES IN FY 2017

None.

## ACHIEVEMENTS IN FY 2015

NASA continued to execute restoration activities at all NASA Centers and facilities. Most notably, the following restoration activities were accomplished in FY 2015:

- SSFL began demolition of buildings not associated with test stands and development of work plans for soil cleanup, continued soil and groundwater cleanup treatability studies, groundwater field investigations, operations of groundwater treatment system and long-term monitoring of groundwater. Prepared cultural resource actions per the Programmatic Agreement with State

Historic Preservation Office (SHPO), Native Americans and consulting parties and continued to Support California in its CEQA work and the National Parks Service documenting historic structures and possible monument analysis.

- MSFC completed cleanup activities at the former Stauffer Chemical Plant site, a time critical removal for the Industrial Sewer operable unit and an interim remedial action at the Source Area 2 Groundwater site and began design activities for the cleanup of petroleum-contaminated sites at the Center.
- WSTF continued to operate the plume front and mid-plume front treatment systems to capture and treat contaminated groundwater. They also continued source area investigations and closure activities of the sewage lagoon.
- KSC installed several new groundwater treatment systems, completed extensive contaminated soil removal at various sites, continued sampling of over 400 monitoring wells, and continued operations of existing groundwater cleanup systems.
- At JPL, the program continued to operate and maintain systems to clean up contaminated groundwater emanating from JPL, as well as operations and system upgrades to the Lincoln Avenue and Monk Hill drinking water treatment systems.

## WORK IN PROGRESS IN FY 2016

- Continue demolition, development of soil cleanup plans, operation of groundwater treatment system and groundwater monitoring at SSFL. Complete groundwater investigation field work, Burro Flats delineation, Extended Phase 1 survey, and Ethnographic study per Programmatic Agreement with SHPO, Native Americans and consulting parties and support California in its CEQA work;
- Continue operations and maintenance of systems to clean up contaminated groundwater emanating from JPL, install second new recovery wells, connect existing backwash system to the treatment facility, and continue operations of the Lincoln Avenue and Monk Hill drinking water treatment systems;
- Continue investigation and cleanup of groundwater and soil contamination at KSC in accordance with State of Florida requirements. Actions planned include the installation of new groundwater treatment systems, extensive contaminated soil removal, investigation of additional sites for potential contamination, continued sampling of over 400 monitoring wells, and continued operations of groundwater cleanup systems;
- Continue cleanup of ground water contamination and investigation of soil contamination at in the WSTF, to comply with the facility permit issued by the State of New Mexico. Key achievements include closure activities, implementation of source area facility investigations, and continued operation of the plume front and mid-plume ground water treatment systems; and
- Continue studies, investigations, and begin the cleanup of the peninsula solid waste disposal site at ARC.

# ENVIRONMENTAL COMPLIANCE AND RESTORATION

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

Key projects and achievements in the FY 2017 request include:

- $38.0 million for cleanup of contaminated groundwater and soil removal, operations of groundwater treatment systems, and continued long term monitoring of the groundwater at SSFL in accordance with the consent order with the State of California;
- $10.5 million for continued cleanup of ground water contamination and investigation of soil contamination at WSTF, to comply with the facility permit issued by the State of New Mexico. Key achievements include completion of closure activities, implementation of source area facility investigations, long term monitoring of groundwater, and continued operation of the plume front and mid-plume ground water treatment systems;
- $13.5 million for continued investigation and cleanup of groundwater and soil contamination at KSC in accordance with State of Florida requirements. Key achievements planned include the installation of new groundwater treatment systems, removal of contaminated soils, investigation of additional sites for potential contamination, continued sampling of over 400 monitoring wells, and continued operations of groundwater cleanup systems; and
- $10.0 million to operate and maintain systems to clean up contaminated groundwater emanating from JPL and operations of the Lincoln Avenue and Monk Hill drinking water treatment systems.

# Program Elements

## RESTORATION

Restoration projects address cleanup liabilities at all NASA Centers and component facilities. As of the start of FY 2016, known liabilities totaled $1.2 billion with many of the individual cleanup projects estimated to take more than 30 years to complete. NASA policy is to address these liabilities using a "worst first" approach to ensure human health and the environment are protected and to facilitate mission readiness. Plans for FY 2017 are based on a prioritized, risk-based approach for incrementally addressing NASA's cleanup portfolio. Projects are ranked according to the relative urgency and the potential health and safety hazards related to each individual cleanup. As studies, assessments, investigations, plans, regulatory approvals, and designs progress, and as new discoveries or regulatory requirements change, NASA expects that program priorities may change.

## ENVIRONMENTAL COMPLIANCE AND FUNCTIONAL LEADERSHIP

Environmental Compliance and Functional Leadership projects invest in environmental methods and risk reduction practices that ensure NASA may continue to carry out its scientific and engineering missions. This includes methodologies for sustainably reducing energy intensity and greenhouse gas emissions, and supporting operational activities by ensuring that advances in chemical risk management are incorporated early in mission design phases. For example, NASA is working with the European Space Agency on an international agreement to investigate methods of increasing energy and water resiliency in critical space mission supporting infrastructure, thus increasing that infrastructure reliability.

# INSPECTOR GENERAL

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **37.0** | **37.4** | **38.1** | **38.9** | **39.6** | **40.4** | **41.2** |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016.*

# INSPECTOR GENERAL

## FY 2017 Budget

| Budget Authority (in $ millions) | Actual FY 2015 | Enacted FY 2016 | Request FY 2017 | Notional FY 2018 | FY 2019 | FY 2020 | FY 2021 |
|---|---|---|---|---|---|---|---|
| **Total Budget** | **37.0** | **37.4** | **38.1** | **38.9** | **39.6** | **40.4** | **41.2** |
| Change from FY 2016 | | | **0.7** | | | | |
| Percentage change from FY 2016 | | | **1.9%** | | | | |

*FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235.*

*FY 2016 reflects only funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016.*

For FY 2017, the NASA Office of Inspector General (OIG) requests $38.1 million to support the work of 192 auditors, investigators, analysts, specialists, lawyers, and support staff located at NASA Headquarters in Washington, DC, and 12 other locations throughout the United States.

The OIG conducts audits, investigations, and reviews of NASA programs to prevent and detect fraud, waste, abuse, and mismanagement and to assist NASA management in promoting economy, efficiency, and effectiveness in its programs and operations. Our operational offices are the Office of Audits (OA) and the Office of Investigations (OI).

OA conducts independent and objective audits of NASA programs, projects, operations, and contractor activities and oversees the work of the independent public accounting firm that conducts the annual audit of NASA's financial statements. In its work, OA targets high-risk areas and NASA's top management challenges. OIG audits provide independent assessments and actionable recommendations that help NASA achieve its space exploration, scientific, and aeronautics research missions.

OI pursues allegations of cybercrime, fraud, waste, abuse, and misconduct related to NASA programs, projects, personnel, operations, and resources. OI refers its findings to the Department of Justice for criminal prosecution and civil litigation or to NASA management for administrative action. Through its investigations, OI develops recommendations to reduce the Agency's vulnerability to criminal activity or administrative inefficiency. Given that NASA spends approximately 79 percent of its budget on contracts and grants, OI targets its resources to maintaining the integrity of NASA's procurement process and the security of NASA's mission and information systems. In the procurement area, OI's caseload includes investigations of suspected false claims submitted by NASA contractors, product substitution and counterfeit parts, and conflict of interest cases that involve NASA employees who place private gain before public service.

### EXPLANATION OF MAJOR CHANGES IN FY 2017

No major changes.

### ACHIEVEMENTS IN FY 2015

In FY 2015, the OIG issued 24 audit products and identified approximately $98.9 million in potential savings for NASA. Audit products included reports examining NASA's:

- Response to Orbital's October 2014 Launch Failure;
- Oversight of International Space Station Operations and Maintenance Contracts;
- Implementation of the Joint Cost and Confidence Level Process;
- Management of the Deep Space Network;
- Pressure Vessels and Pressurized Systems Program; and
- Efforts to Prevent Excessive Incurred Costs on Cost-type Contracts.

In FY 2015, OI investigated a wide variety of criminal and administrative matters involving procurement fraud, theft, counterfeit parts, ethics violations, and computer intrusions leading to more than $86 million in criminal, civil, and administrative penalties and settlements. More than $10.3 million of these funds were returned directly to NASA. Overall, OI's efforts in FY 2015 resulted in 30 indictments, 29 convictions, 10 civil settlements, 26 administrative actions, and 33 suspensions or debarments.

- Examples of OI's work over the past year include:
- A husband and wife were sentenced to 15 and 13 years' imprisonment, respectively, and ordered to pay $10.7 million in restitution after being convicted of fraudulently obtaining more than $10 million in Small Business Innovation Research (SBIR) contracts from NASA and other Federal agencies. The couple submitted research proposals using stolen identities in order to create false endorsements for their proposed contracts and lied about facilities, costs, the principal investigator on some of the contracts, and certifications included in the proposals;
- A business owner was convicted of seven counts of wire fraud following a joint investigation conducted by the NASA OIG, the National Science Foundation OIG, and the U.S. Secret Service. The investigation revealed the owner received nearly $800,000 in grant funds and spent the funds almost entirely on personal expenses such as mortgage payments, private school tuition for his children, vacations, shopping, and wire transfers to family and friends overseas;
- The CEO of a NASA contractor conducting business at the Johnson Space Center was sentenced to 3 years' imprisonment and 1 year of supervised release for making false statements on a federal income tax return. As part of a plea agreement, the CEO agreed to make restitution of $294,300 related to the tax violations and to pay NASA $99,000 as reimbursement for questioned consulting services;
- Another CEO agreed to pay $4.5 million to settle a civil claim after being found guilty of fraudulently obtaining Government contracts set aside for small businesses; and
- Three Estonian nationals were sentenced to 40 months in prison and ordered to forfeit between $1 million and $2.5 million each for their role in a fraud scheme that caused malware to infect NASA computer systems and millions of additional systems worldwide.

## WORK IN PROGRESS IN FY 2016

During FY 2016, the OIG will continue to conduct audits, reviews, and investigations of NASA programs and operations to prevent and detect fraud, waste, abuse, and mismanagement and to assist NASA in promoting economy, efficiency, and effectiveness. Projects on which our auditors are currently working include NASA's management of the Orion Crew Vehicle and Commercial Crew Programs, its response to the SpaceX June 2015 launch failure, and its management of its Earth science portfolio.

Ongoing OI work includes proactive initiatives designed to identify a variety of common acquisition and procurement fraud schemes. Additionally, representatives from both OI and OA are working together to use data analytics and information technology resources as a means of identifying indicators of potential fraudulent activity.

## KEY ACHIEVEMENTS PLANNED FOR FY 2017

Going forward, the OIG will continue to focus its audit work in the areas the OIG identifies as NASA's top management and performance challenges. In a November 2015 report, we listed those challenges as:

- Space Flight Operations in Low Earth Orbit: Managing the International Space Station and the Commercial Cargo and Crew Programs;
- Positioning NASA for Deep Space Exploration: Developing the Space Launch System, Orion Capsule, and associated Ground Systems, and Mitigating Health and Performance Risks for Extended Human Missions;
- Managing NASA's Science Portfolio;
- Ensuring the Continued Efficacy of the Space Communications Networks;
- Overhauling NASA's Information Technology Governance;
- Securing NASA's Information Technology Systems and Data;
- Managing NASA's Aging Infrastructure and Facilities; and
- Ensuring the Integrity of the Agency's Contracting and Grants Processes.

The OIG's FY 2017 request is $38.1 million, and includes the following:

- $32.3 million (85 percent) for personnel and related costs, including salaries, benefits, monetary awards, worker's compensation, permanent change of station costs, and Government contributions for Social Security, Medicare, health and life insurance, retirement accounts, and Thrift Savings Plan accounts. Salaries include the required additional 25 percent law enforcement availability pay (LEAP) for criminal investigators;
- $1.1 million (3 percent) for travel, per diem, and related expenses;
- $2.3 million (6 percent) to fund the required annual audit of NASA's financial statements: The cost of the annual audit was reduced by $0.7 million from the prior year due to a change in service provider; and
  $2.4 million (6 percent) for equipment, training, government vehicles, special equipment for criminal investigators, transit subsidies, and IT equipment unique to the OIG.[1]

[1] *This number includes $500,000 for staff training and $100,000 to support the Council of Inspectors General on Economy and Efficiency (CIGIE). In accordance with Public Law 110-409, the Inspector General Reform Act of 2008, the Inspector General certifies that these amounts are sufficient to satisfy all training requirements and contributions to CIGI.*

# Supporting Data

# FUNDS DISTRIBUTION BY INSTALLATION

## FUNDS BY MISSION BY NASA CENTER

| Budget Authority ($ in millions) | **FY 2017*** |
|---|---|
| Science | 207.9 |
| Aeronautics | 133.6 |
| Space Technology | 42.9 |
| Exploration | 55.4 |
| Space Operations | 25.7 |
| Education | 0.9 |
| Safety, Security, and Mission Services | 217.0 |
| Construction and Environmental Compliance and Restoration | 66.2 |
| **Ames Research Center (ARC) Total** | **749.7** |
| Science | 66.4 |
| Aeronautics | 84.0 |
| Space Technology | 16.6 |
| Exploration | 25.3 |
| Space Operations | 0.1 |
| Education | 0.8 |
| Safety, Security, and Mission Services | 61.8 |
| Construction and Environmental Compliance and Restoration | 18.4 |
| **Armstrong Flight Research Center (AFRC) Total** | **273.4** |
| Science | 28.2 |
| Aeronautics | 135.8 |
| Space Technology | 89.3 |
| Exploration | 57.8 |
| Space Operations | 57.4 |
| Education | 1.0 |
| Safety, Security, and Mission Services | 212.3 |
| Construction and Environmental Compliance and Restoration | 15.9 |
| **Glenn Research Center (GRC) Total** | **597.7** |
| Science | 2,429.2 |
| Space Technology | 160.7 |
| Exploration | 23.3 |
| Space Operations | 248.7 |
| Education | 1.4 |
| Safety, Security, and Mission Services | 408.1 |
| Construction and Environmental Compliance and Restoration | 3.7 |
| **Goddard Space Flight Center (GSFC) Total** | **3,275.1** |

# FUNDS DISTRIBUTION BY INSTALLATION

| Budget Authority ($ in millions) | FY 2017* |
|---|---|
| Science | 1,148.5 |
| Space Technology | 34.9 |
| Exploration | 51.7 |
| Space Operations | 172.9 |
| Education | 2.0 |
| Safety, Security, and Mission Services | 15.4 |
| Construction and Environmental Compliance and Restoration | 37.0 |
| **Jet Propulsion Laboratory (JPL) Total** | **1,462.5** |
| Science | 22.9 |
| Space Technology | 18.0 |
| Exploration | 1,212.5 |
| Space Operations | 2,858.9 |
| Education | 1.3 |
| Safety, Security, and Mission Services | 361.9 |
| Construction and Environmental Compliance and Restoration | 37.0 |
| **Johnson Space Center (JSC) Total** | **4,512.5** |
| Science | 313.6 |
| Space Technology | 9.3 |
| Exploration | 437.2 |
| Space Operations | 1,338.6 |
| Education | 1.1 |
| Safety, Security, and Mission Services | 347.0 |
| Construction and Environmental Compliance and Restoration | 27.0 |
| **Kennedy Space Center (KSC) Total** | **2,473.8** |
| Science | 196.6 |
| Aeronautics | 182.1 |
| Space Technology | 32.4 |
| Exploration | 49.4 |
| Space Operations | 2.0 |
| Education | 1.3 |
| Safety, Security, and Mission Services | 281.1 |
| Construction and Environmental Compliance and Restoration | 24.0 |
| **Langley Research Center (LaRC) Total** | **768.6** |

# FUNDS DISTRIBUTION BY INSTALLATION

| Budget Authority ($ in millions) | **FY 2017*** |
|---|---|
| Science | 134.3 |
| Space Technology | 27.2 |
| Exploration | 1,241.8 |
| Space Operations | 205.7 |
| Education | 1.1 |
| Safety, Security, and Mission Services | 429.9 |
| Construction and Environmental Compliance and Restoration | 96.8 |
| **Marshall Space Flight Center (MSFC) Total** | **2,136.9** |
| Science** | 1,050.7 |
| Aeronautics | 254.8 |
| Space Technology** | 393.7 |
| Exploration | 141.4 |
| Space Operations | 130.4 |
| Education | 88.5 |
| Safety, Security, and Mission Services | 449.6 |
| Construction and Environmental Compliance and Restoration | 69.7 |
| Office of Inspector General | 38.1 |
| **NASA Headquarters (HQ) and Inspector General (IG) Total** | **2,619.0** |
| Science | 0.2 |
| Space Technology | 1.7 |
| Exploration | 41.1 |
| Space Operations | 35.6 |
| Education | 0.7 |
| Safety, Security, and Mission Services | 52.7 |
| Construction and Environmental Compliance and Restoration | 24.1 |
| **Stennis Space Center (SSC) Total** | **156.0** |
| **Total** | **19,025.1** |

**Totals may not add due to rounding.*

***Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2017 allocations should not be considered final or directly comparable to prior year allocations.*

# CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

NASA's workforce continues to be one of its greatest assets for enabling missions in space and on Earth. The Agency remains committed to applying this asset to benefit society, address contemporary environmental and social issues, lead or participate in emerging technology opportunities, collaborate and strengthen the capabilities of commercial partners, and communicate the challenges and results of Agency programs and activities. The civil service staffing levels proposed in the Fiscal Year (FY) 2017 budget support NASA's scientists, engineers, researchers, managers, technicians, and business operations workforce. It includes civil service personnel at NASA Centers, Headquarters, and NASA-operated facilities. However, the mix of skills and distribution of workforce across the Agency is necessarily changing.

NASA continues to adjust its workforce size and mix of skills to address changing mission priorities, with an emphasis on industry and academic partnerships, transferring work in-house from on- and near-site support contracts, and operating in a leaner fiscal environment. A civil service workforce is critical for conducting mission-essential work in research and technology. As NASA continues to seek to have the right workforce to meet its requirements, some reduction to workforce levels is necessary. NASA will make modest reductions to the size of the civil service workforce with a decrease of more than 50 full-time equivalents from FY 2016 to FY 2017, bringing the civil service workforce to approximately 17,150 full-time equivalents (FTEs).

NASA will continue to explore opportunities across the Agency to insource work and find efficiencies in workforce productivity, especially in mission support functional areas. The Agency will apply the valued civil service workforce to priority mission work, adjusting the mix of skills where appropriate. Centers will explore cross-mission retraining opportunities for employees whenever possible, offer targeted buyouts in selected surplus skill areas, and continue to identify, recruit, and retain a multi-generational workforce of employees who possess skills critical to the Agency.

## CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION BY CENTER

| | Actual | Estimate | Request | Notional | | | |
|---|---|---|---|---|---|---|---|
| | **FY 2015** | **FY 2016** | **FY 2017** | **FY 2018** | **FY 2019** | **FY 2020** | **FY 2021** |
| ARC | 1,154 | 1,165 | 1,160 | 1,160 | 1,160 | 1,160 | 1,160 |
| AFRC | 536 | 538 | 537 | 538 | 538 | 538 | 538 |
| GRC | 1,548 | 1,546 | 1,539 | 1,543 | 1,543 | 1,543 | 1,543 |
| GSFC | 3,189 | 3,265 | 3,262 | 3,260 | 3,262 | 3,262 | 3,262 |
| JSC | 2,974 | 2,979 | 2,961 | 2,963 | 2,962 | 2,962 | 2,962 |
| KSC | 1,952 | 1,976 | 1,967 | 1,957 | 1,957 | 1,957 | 1,957 |
| LaRC | 1,859 | 1,821 | 1,809 | 1,809 | 1,809 | 1,809 | 1,809 |
| MSFC | 2,351 | 2,334 | 2,323 | 2,328 | 2,327 | 2,327 | 2,327 |
| SSC | 304 | 311 | 304 | 305 | 305 | 305 | 305 |
| HQ | 1,112.8 | 1,145 | 1,154 | 1,154 | 1,154 | 1,154 | 1,154 |
| NSSC | 128.9 | 141 | 140 | 140 | 140 | 140 | 140 |
| **NASA Total*** | **17,108** | **17,220** | **17,156** | **17,157** | **17,157** | **17,157** | **17,157** |
| OIG | 194 | 213 | 213 | 213 | 213 | 213 | 213 |

**Totals may not add due to rounding. All actuals and estimates include direct-funded and reimbursable FTE.*

***Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2017 allocations should not be considered final or directly comparable to prior year allocations.*

# CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

## FY 2017 FTE DISTRIBUTION BY ACCOUNT BY CENTER

| | Science | Aeronautics | Space Technology | Exploration | Space Operations | Education | Safety, Security, and Mission Services | Reimbursable / Working Capital Fund** | NASA-Funded Total | Agency TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| ARC | 135 | 235 | 96 | 99 | 25 | 6 | 542 | 22 | 1,138 | 1,160 |
| AFRC | 100 | 169 | 13 | 21 | 1 | 5 | 213 | 15 | 522 | 537 |
| GRC | 76 | 362 | 135 | 196 | 150 | 7 | 611 | 3 | 1,536 | 1,539 |
| GSFC | 1,181 | 0 | 138 | 17 | 130 | 7 | 1,569 | 219 | 3,043 | 3,262 |
| JSC | 31 | 0 | 64 | 736 | 1,268 | 7 | 855 | 0 | 2,961 | 2,961 |
| KSC | 1 | 0 | 50 | 569 | 478 | 7 | 856 | 7 | 1,960 | 1,967 |
| LaRC | 209 | 489 | 117 | 130 | 7 | 8 | 834 | 15 | 1,794 | 1,809 |
| MSFC | 130 | 0 | 97 | 853 | 227 | 7 | 1,009 | 0 | 2,323 | 2,323 |
| SSC | 0 | 0 | 5 | 68 | 40 | 5 | 151 | 36 | 269 | 304 |
| HQ | 12 | 0 | 7 | 0 | 0 | 0 | 1,135 | 0 | 1,154 | 1,154 |
| NSSC | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 140 | 0 | 140 |
| **NASA Total*** | **1,875** | **1,255** | **722** | **2,688** | **2,325** | **60** | **7,775** | **457** | **16,699** | **17,156** |
| OIG | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 213 |

**Totals may not add due to rounding.*

***Includes 140 FTE funded by Working Capital Fund; and 317 FTE funded by reimbursable customers.*

****Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2017 allocations should not be considered final or directly comparable to prior year allocations.*

# WORKING CAPITAL FUND

NASA established the Working Capital Fund (WCF) to satisfy specific recurring needs for goods and services through use of a business-like buyer and seller approach under which NASA's WCF entities provide goods or services pursuant to contracts and agreements with their customers. The overarching aim of WCF is to promote economy, efficiency, and accountability with fully reimbursed rates by focusing on streamlining operations, extending resources, measuring performance, and improving customer satisfaction.

NASA's WCF is comprised of three entities:

- NASA Shared Services Center (NSSC);
- Solutions for Enterprise-Wide Procurement (SEWP) Government-Wide Acquisition Contract; and
- Information Technology (IT) Infrastructure Integration Program (I3P).

## WORKING CAPITAL FUNDS BUDGET SUMMARY

| Spending Authority from Offsetting Collections ($ millions) | Actual<br>FY 2015 | Estimate<br>FY 2016 | Request<br>FY 2017 |
|---|---|---|---|
| NSSC | 76 | 75 | 88 |
| SEWP | 11 | 17 | 17 |
| I3P | 332 | 373 | 356 |
| **Total Spending Authority** | **419** | **465** | **460** |
| Unobligated Brought Forward, Oct. 1 | 11 | 10 | 3 |
| Recoveries of Prior Yr. Unpaid Obligations | 0 | 4 | 0 |
| **Total Budgetary Resources** | **430** | **479** | **463** |
| NSSC | 77 | 87 | 88 |
| SEWP | 11 | 15 | 14 |
| I3P | 332 | 375 | 356 |
| **Total Obligations** | **420** | **477** | **458** |
| **Unobligated Balance (end-of-year)*** | **10** | **3** | **6** |

**Unobligated balance end-of-year is budgetary resources less obligation*

## NASA SHARED SERVICES CENTER (NSSC)

NSSC opened in March 2006 to provide centralized administrative processing services and customer contact center operations for support of human resources, procurement, financial management, Agency IT, and Agency business support services. NASA established NSSC, a function under the NASA Headquarters Mission Support Directorate, as a public/private partnership. NSSC has awarded its major business management and IT services contract to Computer Sciences Corporation. Typical expenditures are related to civil service workforce, support contractor, other direct procurements, and Agency training purchases.

NSSC is located on the grounds of SSC and operates in a manner that provides for transparency and accountability of costs and services. NASA has reduced its administrative costs through centralized processing at NSSC. The work performed by NSSC reduces duplicative efforts and increases cost efficiencies.

NSSC's revenue streams include funding from the NASA Centers, mission directorates, and various NASA mission support offices. During FY 2017, NSSC will continue to offer similar services as in FY 2016 with no significant scope changes anticipated.

## SOLUTIONS FOR ENTERPRISE-WIDE PROCUREMENT (SEWP)

SEWP refers to operations related to the Government-Wide Acquisition Contract that was established under the authority of section 5112 of the Information Technology Management Reform Act (40 U.S.C. 1412(e)), enacted in 1996, under which NASA is designated by the Office of Management and Budget (OMB) as a Federal Government Executive Agent for SEWP contracts.

SEWP was established as a WCF entity to allow all Federal agencies use of a best value tool to purchase IT product solutions and services. Under this approach, the buying power of Federal Agencies is combined to acquire best value for IT products and services more efficiently. Typical acquisitions include a wide range of advanced technologies such as UNIX-Linux and Windows-based desktops and servers, along with peripherals, network equipment, storage devices, security tools, software, and other IT products and product-based solutions.

SEWP promotes aggressive pricing using online tools to obtain multiple, competitive quotes from vendors. On average for FY 2016, SEWP quotes have a 20-percent savings for any Federal customer using SEWP contracts. In addition, SEWP offers a low surcharge to recover NASA's costs to operate the program with an average 0.39 percent fee as compared to the Government standard of 0.75 percent. SEWP revenue is generated solely from the surcharge fees on all transactions processed. For FY 2016, the Federal Government is projected to save about $8.7 million in service fees, based on the difference between General Services Administration (GSA) and SEWP surcharge fees.

## IT INFRASTRUCTURE INTEGRATION PROGRAM (I3P)

WCF operations supporting I3P began in early FY 2012. WCF enables I3P to improve the efficiency and economy in which contract services and management are provided to support NASA's IT strategic initiatives and to increase visibility into NASA's IT budget and expenditures. Under I3P, NASA has consolidated 19 separately managed contracts into 4 centrally managed ones described as follows:

- The Enterprise Applications Service Technologies contract supports NASA Enterprise Applications Competency Center (NEACC) applications hosted by MSFC. The NEACC operates and maintains a broad spectrum of NASA's enterprise applications, with an emphasis on fully integrating business process expertise with application and technical knowledge. A small team of civil servants and support contractors sustain operations, implement new applications and capabilities, and provide business readiness support to the stakeholders and end-users.
- The NASA Integrated Communications Services contract provides wide and local area network, telecommunications, video, and data services hosted at MSFC.

- The Web Enterprise Service Technologies contract provides public Web site hosting, Web content management and integration, and search services. GSFC and ARC host these services.
- The Agency Consolidated End-User Services contract provides program management, provisioning, and support of desktops, laptops, cell phones, personal digital assistants, office automation software, and video conferencing. NSSC hosts these services.

I3P's consolidated contracting approach benefits NASA by providing cost saving opportunities, such as the reduction in administrative burden involved with the business management of contracts and a significant reduction in procurement request transaction volume. Other I3P benefits include the streamlining budgeting, funding, and costing of I3P services; achieving transparency through the provision of detailed customer monthly billings; and providing consolidated, consistent reporting of Agency-wide consumption of I3P-related goods and services.

I3P is unique in that revenue streams and expenditures are limited to contract costs for its four service contracts. Revenue streams include funding from the NASA Centers, NASA Mission Directorates, and various NASA mission support offices. As reflected in the FY 2017 anticipated funding level, the I3P WCF will continue to offer similar services as in FY 2016.

# BUDGET BY OBJECT CLASS

| FY 2017 Estimated Direct Discretionary and Mandatory Obligations ($ millions)<br>Code | Object Class | Science | Aeronautics | Space Technology | Exploration | Space Operations | Education | Safety, Security, and Mission Services | Construction & Environmental Compliance & Restoration | Office of Inspector General | NASA Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 11.1 | Full-time permanent | 249 | 156 | 87 | 380 | 262 | 7 | 989 | 0 | 24 | 2,154 |
| 11.3 | Other than full-time permanent | 4 | 3 | 1 | 2 | 2 | 0 | 19 | 0 | 0 | 33 |
| 11.5 | Other personnel compensation | 2 | 0 | 0 | 1 | 1 | 0 | 25 | 0 | 0 | 31 |
| 11.8 | Special personal service payments | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 2 |
| *11.9* | *Subtotal Personnel Compensation* | *255* | *160* | *89* | *384* | *266* | *7* | *1,034* | *0* | *25* | *2,220* |
| 12.1 | Civilian personnel benefits | 75 | 47 | 27 | 119 | 81 | 2 | 302 | 0 | 10 | 663 |
| 13.0 | Benefits to former personnel | 0 | 0 | 0 | 1 | 1 | 0 | 3 | 0 | 0 | 6 |
| | **Total Personnel Compensation & Benefits** | **331** | **207** | **116** | **504** | **348** | **10** | **1,339** | **0** | **35** | **2,888** |
| 21.0 | Travel & transport. of persons | 24 | 8 | 5 | 16 | 12 | 0 | 2 | 0 | 0 | 67 |
| 22.0 | Transportation of things | 12 | 1 | 2 | 8 | 1,187 | 0 | 4 | 0 | 0 | 1,214 |
| 23.1 | Rental payments to GSA | 0 | 0 | 0 | 0 | 0 | 0 | 35 | 0 | 0 | 35 |
| 23.2 | Rental payments to others | 5 | 0 | 0 | 0 | 3 | 0 | 4 | 0 | 0 | 12 |
| 23.3 | Communications, utilities & misc. | 4 | 3 | 0 | 4 | 2 | 0 | 67 | 2 | 0 | 82 |
| 24.0 | Printing & reproduction | 2 | 0 | 0 | 0 | 1 | 0 | 4 | 0 | 0 | 7 |
| 25.1 | Advisory & assistance services | 87 | 12 | 25 | 325 | 73 | 7 | 185 | 20 | 0 | 734 |
| 25.2 | Other services | 202 | 32 | 33 | 40 | 99 | 9 | 282 | 40 | 2 | 739 |
| 25.3 | Other purchases of goods & services from Government accounts | 153 | 8 | 9 | 48 | 25 | 0 | 45 | 16 | 1 | 305 |
| 25.4 | Operation & maintenance. of facilities | 17 | 34 | 2 | 115 | 51 | 0 | 153 | 38 | 0 | 410 |
| 25.5 | Research & development contracts | 3,959 | 354 | 622 | 1,977 | 2,912 | 9 | 158 | 20 | 0 | 9,248 |
| 25.6 | Medical care | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 1 | 0 | 9 |
| 25.7 | Operation & maintenance of equipment | 81 | 37 | 8 | 109 | 282 | 4 | 446 | 1 | 0 | 968 |
| 26.0 | Supplies & materials | 31 | 14 | 3 | 22 | 16 | 0 | 19 | 0 | 0 | 105 |

# BUDGET BY OBJECT CLASS

| Code | FY 2017 Estimated Direct Discretionary and Mandatory Obligations ($ millions)<br>Object Class | Science | Aeronautics | Space Technology | Exploration | Space Operations | Education | Safety, Security, and Mission Services | Construction & Environmental Compliance & Restoration | Office of Inspector General | NASA Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 31.0 | Equipment | 49 | 33 | 2 | 62 | 18 | 0 | 37 | 0 | 0 | 201 |
| 32.0 | Land & structures | 0 | 2 | 0 | 33 | 0 | 0 | 27 | 282 | 0 | 344 |
| 41.0 | Grants, subsidies, & contributions | 643 | 45 | 0 | 74 | 49 | 61 | 22 | 0 | 0 | 894 |
| 99.5 | Below reporting threshold | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Other Object Classes** | **5,269** | **583** | **711** | **2,833** | **4,728** | **90** | **1,498** | **420** | **3** | **16,137** |
| | **NASA Total, Direct*** | **5,600** | **790** | **827** | **3,337** | **5,076** | **100** | **2,837** | **420** | **38** | **19,025** |

**Totals may not add due to rounding*

# STATUS OF UNOBLIGATED FUNDS

The table below displays actual and estimated unobligated balances of direct discretionary budget authority in each NASA appropriation account at the end of each fiscal year. The data is non-comparable, or based solely on an appropriation account's activity or projected activity with no adjustment to the FY 2015 or FY 2016 amounts to make them comparable to the budget structure underlying the FY 2017 request.

## UNOBLIGATED FUNDS SUMMARY BY APPROPRIATIONS ACCOUNT

| Budget Authority ($ millions) | Unobligated Balances FY 2015 | Estimated Unobligated Balances FY 2016 | Estimated Unobligated Balances FY 2017 |
|---|---|---|---|
| Science | 338 | 287 | 288 |
| Aeronautics | 25 | 21 | 26 |
| Space Technology | 57 | 34 | 41 |
| Exploration | 40 | 58 | 48 |
| Space Operations | 171 | 184 | 185 |
| Education | 33 | 24 | 21 |
| Safety, Security, and Mission Services | 29 | 21 | 22 |
| Construction and Environmental Compliance and Restoration | 113 | 98 | 106 |
| Science, Exploration, and Aeronautics | 0 | 0 | 0 |
| Office of Inspector General | 1 | 1 | 1 |
| **NASA Total*** | **808** | **728** | **738** |

**Totals may not add due to rounding*

# REIMBURSABLE ESTIMATES

Reimbursable agreements are agreements where the NASA costs associated with the undertaking are borne by the non-NASA partner. NASA undertakes reimbursable agreements when it has equipment, facilities, and services that it can make available to others in a manner that does not interfere with NASA mission requirements. As most reimbursable requests to NASA do not occur until the year of execution, the FY 2016 to FY 2017 estimates are based on an annual survey of Centers' anticipated reimbursable agreements. NASA separately budgets for and executes the three categories of reimbursable agreements listed below. Supporting data for Enhanced Use Leasing is provided on pages SD-14 to SD-15 of this section.

## REIMBURSABLE ESTIMATES BY APPROPRIATIONS ACCOUNT

| Spending Authority from Offsetting Collections ($ millions) | Actual<br>FY 2015 | Estimate<br>FY 2016 | Request<br>FY 2017 |
|---|---|---|---|
| Safety, Security, and Mission Services (non-EUL) | 2,382.0 | 2,692.0 | 2,544.0 |
| Safety, Security, and Mission Services (EUL) | 7.5 | 17.4 | 13.2 |
| Safety, Security, and Mission Services (NHPA) | 5.5 | 12.7 | 12.7 |
| Office of Inspector General | 1.0 | 1.2 | 1.2 |
| **Total** | **2,315.0** | **2,723.3** | **2,571.1** |

# ENHANCED USE LEASING

In 2003, Congress authorized NASA to demonstrate leasing authority and collections at two Centers. In 2007 and 2008, Congress amended that authority such that NASA may enter into leasing arrangements at all Centers. The EUL authority includes a sunset provision (enacted as part of the FY 2009 Omnibus Appropriations Act (P.L. 110-161)) under which NASA's authority will expire on December 26, 2017. NASA has requested in the draft 2017 appropriation language that the sunset provision language be deleted in its entirety so as to make its EUL authority permanent. EUL authority provides NASA the ability to maintain critical facilities and address deferred maintenance challenges as well as support Centers' revitalization plans. Additionally, NASA's EUL Authority supports important relationships with industry, academia, and non-profit organizations.

After deducting the costs of administering the leases, Centers are then permitted to retain 65 percent of net receipt revenue, and the balance is made available Agency-wide for NASA. These funds are in addition to annual appropriations. To ensure annual oversight and review, the 2010 Consolidated Appropriations Act, P.L. 111-117 contains a provision that requires NASA to submit an estimate of gross receipts and collections and proposed use of all funds collected in the annual budget justification submission to Congress. The table below depicts the estimated FY 2017 EUL expenses and revenues. The amounts identified under Capital Asset Account Expenditures may be adjusted between projects listed based on actual contract award. There are no civil servants funded from Enhanced Use Leasing (EUL) income.

## SUMMARY OF FY 2017 EUL ACTIVITY

| FY 2017 EUL Expenses and Revenues ($ thousands) | ARC | GSFC | JPL (NMO) | KSC | MSFC | SSC | Agency | Total |
|---|---|---|---|---|---|---|---|---|
| Base Rent | 6,423.7 | 31.8 | 96.4 | 101.0 | 262.7 | 86.9 | 3,621.1 | 10,623.6 |
| Institutional Support Income | 1,963.1 | 5.0 | 0.0 | 12.8 | 0.0 | 8.6 | 0.0 | 1,989.5 |
| Additional Reimbursable Demand Services Requested by Lessees (including overhead) | 4,122.2 | 0.0 | 0.0 | 49.3 | 0.0 | 0.0 | 0.0 | 4,171.5 |
| **Total Lease Income** | **12,509.0** | **36.8** | **96.4** | **163.1** | **262.7** | **95.5** | **3,621.1** | **16,784.6** |
| Institutional Support Costs | (1,963.1) | (5.0) | 0.0 | (12.8) | 0.0 | (7.0) | 0.0 | (1,987.9) |
| Lease Management and Administration | (881.3) | 0.0 | 0.0 | 0.0 | (6.9) | (1.6) | 0.0 | (889.8) |
| Tenant Building Maintenance and Repair | (1,102.2) | 0.0 | 0.0 | 0.0 | (127.5) | 0.0 | 0.0 | (1,229.7) |
| Cost to Fulfill Reimbursable Demand Services (including overhead) | (4,122.2) | 0.0 | 0.0 | (49.3) | 0.0 | 0.0 | 0.0 | (4,171.5) |
| **Total Cost Associated with Leases** | **(8,068.8)** | **(5.0)** | **0.0** | **(62.1)** | **(134.4)** | **(8.6)** | **0.0** | **(8,278.9)** |
| **Net Revenue from Lease Activity** | **4,440.2** | **31.8** | **96.4** | **101.0** | **128.3** | **86.9** | **3,621.1** | **8,505.7** |
| **Beginning Balance, Capital Asset Account** | **240.0** | **0.0** | **61.0** | **29.7** | **0.0** | **187.5** | **2,800.0** | **3,318.2** |
| **Net Revenue from Lease Activity Retained at Center** | **2,886.1** | **20.7** | **62.7** | **65.7** | **83.4** | **56.5** | **2,977.0** | **6,152.1** |
| **Total Available, Capital Assets Account** | **3,126.1** | **20.7** | **123.7** | **95.4** | **83.4** | **244.0** | **5,777.0** | **9,470.3** |

# ENHANCED USE LEASING

| FY 2017 EUL Expenses and Revenues ($ thousands) | ARC | GSFC | JPL (NMO) | KSC | MSFC | SSC | Agency | Total |
|---|---|---|---|---|---|---|---|---|
| Planned Maintenance, Various Buildings | (1,966.9) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | (1,966.9) |
| Replace Roofs on Various Buildings | (918.2) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | (918.2) |
| Replace Exhaust Fan, B4 Mechanical Room | 0.0 | (20.7) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | (20.7) |
| Rehab. of Vacant Areas to Lease | 0.0 | 0.0 | 0.0 | 0.0 | (83.4) | 0.0 | 0.0 | (83.4) |
| Replace Severely Corroded Piping & Fitting at Riser and at Loading Dock, East End | 0.0 | 0.0 | 0.0 | (63.1) | 0.0 | 0.0 | 0.0 | (63.1) |
| Energy Enhancements | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | (150.0) | 0.0 | (150.0) |
| Energy and Sustainability Upgrades, Various Buildings (Various Centers) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | (3,000.0) | (3,000.0) |
| **Capital Asset Account Expenditures** | **(2,885.1)** | **(20.7)** | **0.0** | **(63.1)** | **(83.4)** | **(150.0)** | **(3,000.0)** | **(6,202.3)** |
| **Capital Asset Account Ending Balance** | **241.0** | **0.0** | **123.7** | **32.3** | **0.0** | **94.0** | **2,777.0** | **3,268.0** |
| **In Kind Activity** | **0.0** | **0.0** | **0.0** | **0.0** | **0.0** | **0.0** | **0.0** | **0.0** |

## DEFINITIONS

### Base Rent

Revenue collected from tenant for rent of land or buildings.

### Institutional Support Costs

Cost for institutional shared services, such as fire, security, first responder, communications, common grounds, road, and infrastructure maintenance, and routine administrative support and management oversight (e.g., environmental).

### Total Rental Income

Total gross proceeds from EUL activities for expenses due to renting NASA property.

### In-Kind

Consideration accepted in lieu of rent payment (only applies to selected leases signed prior to January 1, 2009).

### Reimbursable Demand Services

Services such as janitorial, communications, and maintenance that solely benefit the tenant and are provided for their convenience. There is no net income received by NASA, as these payments may only cover the costs of NASA and its vendors providing these services.

# NATIONAL HISTORIC PRESERVATION ACT

In FY 2014, NASA established a new fund based upon the National Historic Preservation Act (NHPA) of 1966. The Act provides the authority to administer, operate, manage, lease and maintain property, and demolish or remove buildings or space in buildings owned by NASA. It also allows any funds received from leasing the properties, buildings, or space in buildings to be deposited to the credit of a special receipt account and expended for purposes of operating, maintaining, and managing the properties and demolishing or removing the buildings. Agreements or contracts with public or private agencies, corporations, or persons, upon such terms and conditions are allowed. There are no civil servants funded from the NHPA Fund. The NHPA activities will be maintained under NHPA authority under Section 111. These funds are in addition to annual appropriations.

The table below depicts the estimated amounts of anticipated NHPA expenses and revenues for FY 2017. NASA currently expects total rental income of $12.7 million. Of the total rental income of $12.7 million, $4.5 million represents net revenue from lease activities. The net revenue amount of $4.5 million will be used for historic building maintenance and repairs for historic properties at ARC, as well as for other properties throughout the Agency.

| FY 2017 EUL Expenses and Revenues ($ thousands) | **ARC** |
|---|---|
| Base Rent | 10,250.0 |
| Institutional Support Income | 2,481.9 |
| **Total Rental Income** | **12,731.9** |
| Institutional Support Costs | (7,844.4) |
| **Total Cost Associated with Leases** | (343.3) |
| ***Net Revenue from Lease Activity*** | **(8,187.7)** |
| **Beginning Balance, Capital Asset Account** | ***4,544.2*** |
| ***Net Revenue from Lease Activity*** | **0.0** |
| Historic Buildings Maintenance and Repair (ARC) | ***4,544.2*** |
| Historic Buildings Maintenance and Repair (Agency) | (1,471.0) |
| ***Capital Asset Account Expenditures*** | (400.9) |
| **Capital Asset Account Ending Balance** | (2,672.3) |
| Additional Reimbursable Demand Services Requested by Lessees | ***(4,544.2)*** |
| Cost to Fulfill Reimbursable Demand Services | **0.0** |
| **Net activity due to Reimbursable Demand Services** | 4,520.1 |
| **In-Kind Activity** | (4,520.1) |

# NATIONAL HISTORIC PRESERVATION ACT

## DEFINITIONS

### Base Rent

Revenue collected from tenant for rent of land or buildings.

### Institutional Support Costs

Cost for institutional shared services such as fire, security, first responder, communications, common grounds, road, and infrastructure maintenance, and routine administrative support and management oversight (e.g., environmental).

### Total Rental Income

Total gross proceeds from EUL activities for expenses due to renting NASA property.

### In-Kind

Consideration accepted in lieu of rent payment (only applies to selected leases signed prior to January 1, 2009).

### Reimbursable Demand Services

Services such as janitorial, communications, and maintenance that solely benefit the tenant and are provided for their convenience. There is no net income received by NASA, as these payments may only cover the costs of NASA and its vendors providing these services.

# BUDGET FOR MICROGRAVITY SCIENCES

## BUDGET FOR INTERNATIONAL SPACE STATION (ISS) RESEARCH

The Human Exploration and Operations Mission Directorate supports research which takes advantage of the unique environment of reduced gravity on the International Space Station (ISS). ISS Research is conducted in two broad categories: Exploration ISS Research and Non-Exploration ISS Research.

| | Actual | Estimate | Request | Notional | | | |
|---|---|---|---|---|---|---|---|
| Budget Authority ($ millions) | FY 2015 | FY 2016 | FY 2017 | FY 2018 | FY 2019 | FY 2020 | FY 2021 |
| Exploration ISS Research | 162 | 173 | 162 | 158 | 172 | 171 | 170 |
| Non-Exploration ISS Research | 175 | 197 | 191 | 183 | 200 | 207 | 213 |
| **Total** | **337** | **370** | **353** | **341** | **372** | **378** | **383** |
| Percent of Non-Exploration to Total | 52 | 53 | 54 | 54 | 54 | 55 | 56 |

*The amounts included for FY 2015 reflect actual, FY 2016 through FY 2021 are reflective of the NASA outyear planning.*

### Exploration ISS Research

Exploration ISS Research supports the Agency's need for improved knowledge about working and living in space to enable future long-duration human exploration missions.

The Human Research Program provides research results that reduce risks to crew health and performance from prolonged exposure to reduced gravity, space radiation, and isolation during exploration missions. Research on the ISS is mitigating risks to humans in space and on Earth by conducting research in human health countermeasures, space human factors and habitability, behavioral health and performance, and exploration medicine, tools, and technologies.

ISS Research investigates the underlying gravity-dependent phenomena in the following areas: fire prevention, detection, and suppression; boiling; multiphase flow of fluids; and capillary driven flow. These applied research investigations will provide the necessary data for the future design of the following technology areas: life support systems, propellant storage, power generation, thermal control, and advanced environmental monitoring and control.

Funding for the Multi-User System Support (MUSS), which supports Exploration ISS Research, is included in the table above. The MUSS function is responsible for the integration of all ISS payloads including NASA, international partners, and non-NASA users. This includes coordinating payload completion schedules, ISS mission schedules, and the space available on the launch vehicles.

### Non-Exploration ISS Research

NASA allocates at least 15 percent of the funds budgeted for ISS research to ground-based, free-flyer, and ISS life and physical science research that is not directly related to supporting the human space exploration program, in accordance with Section 204 of the NASA Authorization Act of 2005. The purpose is to ensure the capacity to support ground-based research leading to space-based basic and applied scientific research in a variety of disciplines with potential direct national benefits and applications that can be advanced significantly from the uniqueness of microgravity and the space environment. In addition, this allocation allows basic ISS research in fields, including physiological research, basic fluid physics, combustion science, cellular biotechnology, low-temperature physics, cellular research, materials science, and plant research, to be carried out to the maximum extent possible. This research helps to sustain existing U.S. scientific expertise and capability in microgravity research.

The Non-Exploration ISS Research line in the previous table also includes the Alpha Magnetic Spectrometer (AMS) and costs for MUSS support. The AMS is a particle physics and astrophysics experiment, planned for the ISS, which is searching for dark matter, anti-matter, and strange matter.

### Center for the Advancement of Science in Space (CASIS)

The Center for the Advancement of Science in Space (CASIS) is the organization selected by NASA to manage non-NASA use of the ISS National Laboratory in conformance with direction in the 2010 NASA Authorization Act. The Center continues to build momentum in the private sector, and is actively working with leading companies that include Merck, Eli Lilly, COBRA PUMA Golf, Proctor & Gamble, and Novartis. CASIS awarded 39 research and technology projects that include a wide diversity in discipline and application.

CASIS continues to explore new opportunities to develop new research concepts for the ISS, and to implement a value-driven utilization program that brings new users to the ISS research community. CASIS implemented a new research procurement strategy, termed “Sponsored Programs” or solicitations for ISS research, which is financially supported by a sponsor organization focused on solving a specific terrestrial problem. Sponsored programs generate external funding from other outlets and leverage CASIS’s ability to apportion ISS National Lab flight opportunities as an essential conduit to research and innovation. Two sponsored programs in FY 2015 included partnerships with Boeing and the Massachusetts Life Science Center, respectively.

# BUDGET FOR SAFETY OVERSIGHT

The following table provides the safety and mission assurance budget request. This includes the Agency-wide safety oversight functions, as well as the project specific safety, reliability, maintainability, and quality assurance elements embedded within individual projects. NASA does not have a single safety oversight budget line item, but instead amounts are embedded in program, project, and mission support budgets.

## BUDGET SUMMARY FOR SAFETY OVERSIGHT

| | Actual | Estimate | Request | Notional | | | |
|---|---|---|---|---|---|---|---|
| Budget Authority ($ millions) | **FY 2015** | **FY 2016** | **FY 2017** | **FY 2018** | **FY 2019** | **FY 2020** | **FY 2021** |
| Safety and Mission Assurance (AMO) | 48.7 | 49.7 | 51.2 | 52.2 | 53.6 | 54.7 | 55.8 |
| Institutional Operational Safety (CMO) | 33.3 | 32.6 | 36.8 | 38.2 | 38.9 | 39.6 | 40.2 |
| SMA Technical Authority (CMO) | 52.2 | 48.2 | 51.4 | 52.7 | 53.9 | 55.1 | 56.2 |
| **Agency-wide Safety Oversight** | **134.2** | **130.5** | **139.4** | **143.1** | **146.4** | **149.4** | **152.2** |
| **Program Specific** | **300.0** | **300.0** | **300.0** | **300.0** | **300.0** | **300.0** | **300.0** |
| **NASA Total, Safety** | **434.2** | **430.5** | **439.4** | **443.1** | **446.4** | **449.4** | **452.2** |

**Agency-Wide Safety Oversight** – Agency-level programs and activities that support the overarching NASA Safety and Mission Success program.

**Safety and Mission Assurance (S&MA) –** The S&MA program administers and refines the pertinent policies, procedural requirements, and technical safety standards. The program participate in forums that provide advice to the Administrator, Mission Directorates, Program Managers, and Center Directors who are ultimately accountable for the safety and mission success of all NASA programs, projects, and operations. Specific program responsibility includes, among other activities, managing NASA's Orbital Debris program, NASA's Electronic Parts program, and the NASA Safety Center.

**Institutional Operational Safety –** NASA's institutional operational safety program is driven by Occupational Safety and Health Administration (OSHA) 29 Code of Federal Regulations (CFR) 1960, OSHA Standards, NASA Procedural Requirement (NPR) 8715.1, NASA Safety and Health Handbook Occupational Safety and Health Programs, NPR 8715.3, and NASA's general safety program requirements. The program includes construction safety, mishap prevention program including reporting and investigations, safety training, safety awareness, the voluntary protection program, safety metrics and trend analysis, contractor insight/oversight, support to safety boards and committees, support to emergency preparedness and fire safety program, aviation safety, explosives and propellants safety, nuclear safety requirements, radiation safety protection, confined space entry, fall protection, lifting devices, pressure vessel safety, hazard reporting and abatement systems, cryogenic safety, electrical safety requirements (lock out/tag out), facility systems safety, risk management, institutional safety policy development, visitor and public safety, and institutional safety engineering. The institutional operational safety program requires significant federal state and local coordination.

**S&MA Technical Authority and S&MA Support –** The S&MA technical authority program only includes travel and labor for all S&MA supervisors, branch chiefs, or above and designated deputies. In addition, whereas the principal job function of a non-supervisory S&MA person consists of rendering authoritative decisions on S&MA requirements matters that relate to the design or operation of a program or project, that person's salary is included. These positions often are the lead S&MA manager positions for large programs in which the decision-making process is nearly a full time demand. This category does not include salary for those whose work only occasionally falls as an authority task. This includes travel funds in direct support of these individuals.

S&MA is mission support, including administrative support, which cannot be directly charged to a program. This budget includes policy development across the programs, range safety, payload safety (ground processing), independent assessments, metrology and calibration (for center), reliability and maintainability policy, center-wide S&MA program integration and analysis, business and administrative support to S&MA Directorates, and quality assurance for facilities and ground support hardware.

**Program Specific** – Project-specific S&MA costs are included in individual project budgets. These costs include the technical and management efforts of directing and controlling the safety and mission assurance elements of the project. This incorporates the design, development, review, and verification of practices and procedures and mission success criteria intended to ensure that the delivered spacecraft, ground systems, mission operations, and payload(s) meet performance requirements and function for their intended lifetimes.

# PHYSICIAN'S COMPARABILITY ALLOWANCE

The Physicians' Comparability Program permits agencies to provide allowances to certain Federal physicians who enter into service agreements with their agencies to address recruitment and retention problems. Physicians' comparability allowances (PCAs) are critical to NASA's ability to retain flight surgeons and physicians, as well as support NASA's goal of maintaining a stable, high quality physician workforce. NASA's physicians are required to acquire and maintain specialized experience vital to supporting the Agency's missions on the ISS. JSC, NASA's primary user of PCAs is located in Houston, Texas and competes with some of the best medical facilities in the country. The following report summarizes NASA's use of this authority.

## PHYSICIAN'S COMPARABILITY ALLOWANCE (PCA) DATA SUMMARY

| | | Actual<br>FY 2015 | Estimate<br>FY 2016 | Request<br>FY 2017* |
|---|---|---|---|---|
| 1) Number of Physicians Receiving PCAs | | 24 | 25 | 26 |
| 2) Number of Physicians with One-Year PCA Agreements | | 24 | 25 | 26 |
| 3) Number of Physicians with Multi-Year PCA Agreements | | 0 | 0 | 0 |
| 4) Average Annual PCA Physician Pay (without PCA payment) | | $158,569 | $160,630** | $162,236*** |
| 5) Average Annual PCA Payment | | $19,850 | $19,789 | $19,795 |
| 6) Number of Physicians Receiving PCAs by Category (non-add) | Category I Clinical Position | 21 | 22 | 23 |
| | Category II Research Position | 0 | 0 | 0 |
| | Category III Occupational Health | 0 | 0 | 0 |
| | Category IV-A Disability Evaluation | 0 | 0 | 0 |
| | Category IV-B Health and Medical Admin. | 3 | 3 | 3 |

**FY 2017 data will be approved during the FY 2018 Budget cycle*

***Based on estimated 1.3 percent pay increases in 2016*

****Based on estimated 1.0 percent pay increase in 2017*

## MAXIMUM ANNUAL PCA AMOUNT PAID TO EACH CATEGORY OF PHYSICIAN

The allowance amount authorized will be the minimum amount necessary to address the recruitment and retention problems, noted below, and will be determined by considering the factors listed in Code of Federal Resources Title 5 CFR 595.105(a). Allowance amounts may not exceed:

- $14,000 per annum if the employee has served as a Government physician for 24 months or less;
- $24,000 per annum if the employee has served as a Government physician for 24 to 48 months; or
- $30,000 per annum if the employee has served as a Government physician for more than 48 months.

# PHYSICIAN'S COMPARABILITY ALLOWANCE

## RECRUITMENT AND RETENTION ISSUES

### Category 1 Clinical Positions

NASA currently has 21 physicians in this category, all located at JSC in Houston, TX. There are a number of recruitment and retention challenges at JSC:

- The Houston area has world-renowned medical facilities. Physician salaries in the Houston area and across the country continue to rise and compensation at JSC must remain competitive in order to attract and retain high quality physicians.
- JSC's clinical resources continue to focus on support of the International Space Station crew (operating 24/7), support of the active astronaut corps and the operation of the Lifetime Surveillance of Astronaut Health program (which includes all retired astronauts). Physicians at JSC are also using their expertise in aerospace medicine to develop requirements for both the Commercial Crew Program and the Orion Spacecraft development program.
- Physicians who are board-certified in Aerospace Medicine and who have operational experience are a rare and valuable commodity. There is a shortage of aerospace medicine specialists' nationwide and other government and military organizations are actively recruiting qualified physicians.
- Many JSC physicians with aerospace medicine training and experience are also board-certified in other clinical specialties including internal medicine, emergency medicine, and psychiatry. The double board-certified physicians are an especially rare commodity and their dual areas of expertise are extraordinarily valuable to NASA. The training period after medical school, including on-the-job training at NASA after hire, is nearly a full decade. Retaining such physicians after they are hired and have completed NASA Flight Surgeon training requirements is critical to the success of the human space flight program. PCA plays a key part in retaining them.

JSC filled two clinical positions in FY 2015 and the ability to offer PCA continues to be a critical factor in the candidate's decision to accept the employment offer. PCA is an important tool in recruiting new physicians, as the General Schedule salary offered is consistently lower than salaries in the private sector. JSC is planning to hire 2-3 physicians in the next two years in order to meet the Agency's needs. Currently, 32 percent of JSC's physicians are retirement eligible and in the next 5 years, 50 percent will become eligible. JSC must continue to concentrate on retaining physicians and having the capability to fill positions that may become vacant due to resignations and/or retirements. Being able to offer PCA has become increasingly critical to NASA in competing with the private sector for the most qualified physicians.

### Category IV-B Health and Medical Administration

NASA currently has three physicians in this category receiving PCA: two at KSC and one at Headquarters. KSC is not currently experiencing retention issues and has been gradually reducing the PCA amounts with the intent to phase out PCA for the two physicians.

Recruiting and retaining physicians in the Washington, DC area requires NASA to compete with several major medical schools in the Washington, DC area, as well as other Federal agencies such as the National Institutes of Health, Department of Defense, Veterans Administration, Department of Homeland Security, and the Federal Aviation Administration. Physician compensation is commensurately high in this location and competition for qualified physicians is intense. Additionally, attracting physicians from outside the area is difficult due to commuting challenges and the high cost of living.

The Headquarters position is a medical leadership and oversight position that is largely administrative with little opportunity for clinical practice. Many aerospace medicine physicians prefer clinical practice to a medical leadership position. Clinical currency, which is required for licensure and renewal of professional certification, is difficult to maintain while serving in this position. This position is responsible for the success of the medical care system supporting human space flight in the United States and internationally, with significant travel obligations and other pressures associated with this position. These factors also present additional recruitment and retention challenges.

## HOW PCA ALLEVIATES RECRUITMENT AND RETENTION PROBLEMS

PCA continues to be an effective tool at NASA. It has been used successfully at JSC to recruit and retain highly qualified physicians. During FY 2014, JSC had one physician retire and one resign, and these individuals indicated that different professional opportunities, rather than salary, were the main reason for leaving. In FY 15, JSC was able to fill two critical physician positions and experienced no losses because PCA enabled JSC to compete with higher salaries in the private sector. For example, several JSC physicians are board-certified in both aerospace medicine and emergency medicine. These physicians are especially valuable in developing responses to potential medical emergencies during spaceflight or mission training. According to the September 2014 Medical Journal-Houston, the average starting compensation for emergency physicians in the Houston area was $293,729. PCA is used successfully to bridge the widening compensation gap between the private sector and Federal government for such uniquely qualified physicians.

KSC is not currently experiencing retention issues with the two physicians employed there. KSC plans to decrease the current PCA amounts in FY 2016 and phase out PCA in FY 2017 to prevent a negative impact on the income of the two physicians currently receiving PCA.

# PHYSICIAN'S COMPARABILITY ALLOWANCE

## ADDITIONAL INFORMATION

Retaining essential Civil Service physicians will become increasingly critical to maintaining core competencies and fulfilling mission objectives. The multi-year Federal pay freeze caused the gap between Federal and private physician salaries to widen and become more evident. Significantly higher physician pay scales under Title 38 in the Veterans Administration and Department of Defense provide a potential incentive for NASA physicians to continue their government service and receive higher pay by transferring to those agencies. All of these factors affect NASA's ability to attract and retain qualified physicians. PCA is a means to lessen the impact of these factors and provide NASA the ability to continue attracting and retaining qualified physicians.

# Budget for Public Relations

The NASA budget for Public Affairs is funded within Safety, Security, and Mission Services under Center Management and Operations and Agency Management and Operations. All the Installations listed below, except for Headquarters, are in the Center Management and Operations account and the Headquarters budget is in the Agency Management and Operations account.

These budgets include dissemination of information to the news media and the public concerning NASA programs. Content includes support for public affairs/public relations, center newsletters, internal communications, guest operations (including bus transportation), public inquiries, NASA TV, the http://www.nasa.gov portal, and other multimedia support.

## NASA PAO Budget Summary, by Center

| | Actual | Estimate | Request | Notional | | | |
|---|---|---|---|---|---|---|---|
| Budget Authority ($ millions) | **FY 2015** | **FY 2016** | **FY 2017** | **FY 2018** | **FY 2019** | **FY 2020** | **FY 2021** |
| ARC | 2.5 | 2.5 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 |
| AFRC | 1.3 | 1.3 | 1.4 | 1.4 | 1.5 | 1.5 | 1.5 |
| GRC | 2.9 | 2.9 | 3.0 | 3.1 | 3.1 | 3.2 | 3.2 |
| GSFC | 5.8 | 5.8 | 5.9 | 6.0 | 6.0 | 6.1 | 6.2 |
| HQ | 13.5 | 14.0 | 14.9 | 15.4 | 15.7 | 16.1 | 16.3 |
| JSC | 7.5 | 7.6 | 7.7 | 7.7 | 7.7 | 7.7 | 7.7 |
| KSC | 7.1 | 7.6 | 7.8 | 8.0 | 8.3 | 8.6 | 8.8 |
| LaRC | 2.7 | 3.1 | 3.1 | 3.2 | 3.2 | 3.3 | 3.3 |
| MSFC | 5 | 5 | 5.0 | 5.1 | 5.1 | 5.1 | 5.2 |
| SSC | 1.7 | 1.6 | 1.7 | 1.7 | 1.7 | 1.8 | 1.8 |
| **NASA Total** | **50.0** | **51.4** | **53.1** | **54.2** | **54.9** | **56.0** | **56.6** |

*Public Affairs per baseline service level definition as part of the Safety, Security, and Mission Services Budget*

# CONSULTING SERVICES

NASA uses paid experts and consultants to provide advice and expertise beyond that which is available from its in-house civil service workforce. Management controls ensure that there is ample justification for consulting services before these services are obtained. Much of the Agency's expert and consultant support is for the NASA Advisory Council and the Aerospace Safety Advisory Panel. NASA uses experts and consultants to provide expertise on the selection of experiments for future space missions. The use of these experts and consultants provides the Agency with an independent view that assures the selection of experiments likely to have the greatest scientific merit. Other individuals provide independent views of technical and functional problems in order to provide senior management with the widest possible range of information to support making major decisions. Historically, each Mission Directorate engages a few consultants supporting primarily programmatic and Aerospace Safety Advisory Panel issues.

## NASA CONSULTING SERVICES BUDGET SUMMARY

| | Actual | Estimate | Request |
|---|---|---|---|
| (Cost in $ millions) | **FY 2015** | **FY 2016** | **FY 2017** |
| Number of Paid Experts and Consultants | 34.0 | 34.0 | 34.0 |
| Annual FTE Usage | 7.4 | 7.4 | 7.4 |
| Salaries | $0.9 | $0.9 | $0.9 |
| Total Salary and Benefits Costs | $1.0 | $1.0 | $1.0 |
| Travel Costs | $0.2 | $0.2 | $0.2 |
| **Total Costs** | **$1.2** | **$1.2** | **$1.2** |

*FY 2015 are actual obligations. FY 2016 and FY 2017 are estimated Budget Authority*

A broader definition of consulting services could include the total object class "Advisory and Assistance Services" as shown in the Supporting Data Budget by Object Class section of this volume. "Advisory and Assistance Services" include 1) Management and Professional Support Services, 2) Studies, Analysis, and Evaluations, and 3) Engineering and Technical Services.

| | Actual | Estimate | Request |
|---|---|---|---|
| (Cost in $ millions) | **FY 2015** | **FY 2016** | **FY 2017** |
| Advisory and Assistance Services | 739.0 | 722.0 | 734.0 |

## DEFINITIONS

**Consultant** – A person who can provide valuable and pertinent advice generally drawn from a high degree of broad administrative, professional, or technical knowledge or experience. When an agency requires public advisory participation, a consultant also may be a person who is affected by a particular program and can provide useful views from personal experience.

**Expert** – A person who is specially qualified by education and experience to perform difficult and challenging tasks in a particular field beyond the usual range of achievement of competent persons in that field. An expert is regarded by other persons in the field as an authority or practitioner of unusual competence and skill in a professional, scientific, technical, or other activity.

# CONSULTING SERVICES

*These definitions are located under 5 CFR 304.102. The appointments are made under 5 U.S.C. 3109, and the use of this authority is reported to Office of Personnel Management (OPM) annually.*

# E-GOV INITIATIVES AND BENEFITS

## E-GOVERNMENT FUNDING CONTRIBUTIONS AND SERVICE FEES BY INITIATIVE

NASA is providing funding contributions in FY 2017 for each of the following E-Government initiatives:

| Initiative | 2017 Contributions (Includes In-Kind) | 2017 Service Fees* |
|---|---|---|
| E-Rulemaking | 0 | $10,000 |
| Grants.gov | $107,516 | 0 |
| E-Training | 0 | $1,537,500 |
| Recruitment One-Stop | 0 | $115,317 |
| Enterprise Human Resources Integration (EHRI) | 0 | $293,615 |
| E-Payroll | 0 | $3,950,075 |
| E-Travel | 0 | $89,520 |
| Integrated Acquisition Environment (IAE) | 0 | $857,210 |
| Financial Management Lines of Business (LoB) | $124,236 | 0 |
| Human Resources Management LoB | $65,217 | 0 |
| Geospatial LoB | $225,000 | 0 |
| Budget Formulation and Execution LoB** | $110,000 | 0 |
| **NASA Total** | **$631,969** | **$7,203,237** |

**Service fees are estimates as provided by the E-Government initiative managing partners*

***Final FY 2017 commitments have yet to be finalized by Managing Partners (OMB MAX)*

After submission of the budget, NASA will post FY 2017 Exhibit 300 IT business cases on the IT Dashboard, located at: http://it.usaspending.gov/.

The E-Government initiatives serve citizens, businesses, and federal employees by delivering high quality services more efficiently at a lower price. Instead of expensive “stove-piped” operations, agencies work together to develop common solutions that achieve mission requirements at reduced cost, thereby making resources available for higher priority needs. Benefits realized using these initiatives for NASA in FY 2017 are described in the following.

### eRulemaking (Managing Partner Environmental Protection Agency (EPA)) FY 2017 Benefits

NASA’s benefits from the eRulemaking initiative are largely focused on providing the public benefits by providing one-stop access to the Agency’s information on rulemakings and non-rulemaking activities via the Regulations.gov website.

NASA uses the Federal Docket Management System (FDMS) to post its rulemakings in order for the public to gain access to review and comment on these rulemakings. NASA relies on Regulations.gov to retrieve public comments on its rulemakings. NASA’s use of the FDMS and Regulations.gov substantially improves the transparency of its rulemaking actions as this use increases public participation in the regulatory process. Direct budget cost savings and cost avoidance result from NASA’s transition to FDMS and Regulations.gov, enabling the Agency to discontinue efforts to develop, deploy, and operate specific individual online docket and public comment systems. Over a five-year period, NASA is estimated to save over $700,000 over alternative options that would provide similar services.

### Grants.gov (Managing Partner HHS) FY 2017 Benefits

The Grants.gov initiative benefits NASA and its grant programs by providing a single location with broader exposure to publish grant (funding) opportunities and application packages, making the process easier for applicants to apply to multiple agencies. All 26 major Federal grant-making agencies posted 100 percent of their synopses for discretionary funding opportunity announcements on Grants.gov.

In addition, Grants.gov provides a single site for the grantee community to apply for grants using a standard set of forms, processes, and systems giving greater access and ability to apply for Federal funding. Using Grants.gov, NASA is able to reduce operating costs associated with online posting and application of grants. Additionally, the Agency is able to improve operational effectiveness using Grants.gov by increasing data accuracy and reducing processing cycle times.

### e-Training (Managing Partner Office of Personnel Management (OPM)) FY 2017 Benefits

The e-Training initiative provides access to premier electronic training systems and tools that support the training and development of the Federal workforce. The initiative supports agency missions through efficient one-stop access to e-Training products and services. The availability of an electronic training environment enhances the ability of the Federal government and NASA to attract, retain, manage, and develop highly skilled professionals needed for a flexible and high-performing government workforce.

The e-Training initiative benefits NASA by reducing redundancies and achieving economies of scale in the purchase and development of e-learning content and in the purchase of learning technology infrastructure. The System for Administration, Training, and Educational Resources at NASA (SATERN) is a web-based talent management tool that serves as NASA's training system of record. This centralized approach allows NASA to reduce and leverage training costs by eliminating unique systems, standardizing training processes, and valid data.

Through SATERN, employees can view required training, launch online content, view training history, and self-register for approved courses and conferences. In addition, the system allows NASA officials to identify groups and individuals who have not met basic training requirements and ensure accountability for mission critical and federally mandated training and development. SATERN also offers employees access to career planning tools, individual development plans, and competency management assistance. Currently, SATERN offers learners access to more than 2,500 online courses and 18,000 online books and training videos. SATERN is available at all times and can be accessed from work or at home.

### Recruitment One-Stop (Managing Partner OPM) FY 2017 Benefits

USAJOBS simplifies the Federal Job Search Process for Job Seekers and Agencies. The USAJOBS.gov Web site provides a place where citizens can search for employment opportunities throughout the Federal Government. USAJOBS is a fully operational, state of the art recruitment system that simplifies the Federal job search process for job seekers and agencies. Through USAJOBS.gov, users have access to:

- A centralized repository for all competitive service;
- Job vacancies;
- A resume repository used by agencies to identify critical skills;

- A standardized online recruitment tool and services;
- A standard application Process; and
- Intuitive job searches including e-mail notifications for jobs of interest.

Integration with Recruitment One-Stop allows NASA to better attract individuals who can accomplish the Agency's mission. The USAJOBS interface allows job seekers to view and apply for all NASA employment opportunities, as well as those from other federal agencies.

NASA adopted the USAJOBS resume as the basic application document for all NASA positions, except for astronaut positions (in 2005). To date NASA has not identified any specific savings in terms of budgeted savings or cost avoidance. Although the Agency believes that implementation of Recruitment One-Stop has resulted in significant intangible benefits in terms of providing better vacancy information to applicants, it has not resulted in any specific cost savings to NASA. However, the numerous intangible benefits Recruitment One-Stop provides to NASA and other agencies include:

- Decreasing hiring time for managers;
- Providing an integrated solution to agency applicant assessment systems;
- Providing a cost effective marketing and recruitment tool;
- Realizing cost savings over commercial job posting boards;
- Reducing the delay associated with filling critical agency vacancies; and
- Enhancing competition with the private sector for the best and brightest talent for Federal service.

### Enterprise Human Resources Integration (EHRI) (Managing Partner OPM) FY 2017 Benefits

The EHRI program supports the strategic management of human capital by providing agency customers with access to timely and accurate federal workforce data. In support of this objective, EHRI has the following goals: 1) Streamline and automate the exchange of federal employee human resources (HR) information Government-wide; 2) Provide comprehensive knowledge management and workforce analysis, forecasting, and reporting across the Executive Branch; 3) Maximize cost savings captured through automation; and 4) Enhance retirement processing throughout the Executive Branch.

A key initiative of EHRI is the electronic Official Personnel Folder (eOPF), a web-based application capable of storing, processing, and displaying the OPFs of all current, separated, and retired Federal Employees. When fully implemented, the eOPF will cover the entire Executive Branch as well as other Federal and Local Governments with a total user population of more than 1.9 million. The system will replace the existing manual process by automating the Federal Government's HR processes and thereby creating a streamlined Federal HR system for all Federal Employees. The initiative is achieving cost savings that are recognized on a per-folder basis. The total cost avoidance per folder is estimated at $55.56.

Specific EHRI/eOPF benefits to NASA include improved convenience in searching, better security and safety to electronic files, more economical, streamlined business processes, and the ability to have a central repository of OPF records for the Agency. During FY 2010, NASA also deployed the eOPF capability of electronic transfer of eOPFs between agencies. Specific NASA employee benefits include secure online access to OPFs, automatic notification when documents are added, exchange of retirement and HR data across agencies and systems, and the elimination of duplicate and repetitive personnel data in personnel folders. NASA completed its implementation to eOPF in March 2008, and transitioned personnel actions processing to the NASA Shared Service Center.

# E-GOV INITIATIVES AND BENEFITS

## E-Payroll FY 2017 Benefits

The E-Payroll Initiative standardizes and consolidates government-wide federal civilian payroll services and processes by simplifying and standardizing HR/payroll policies and procedures and better integrating payroll, HR, and finance functions. Prior to beginning the initiative, 26 federal agencies provided payroll services. Four providers were selected to furnish payroll services for the Executive branch. Since 2004, the Department of Interior (DOI) has served as NASA's payroll provider, using their system, the Federal Personnel and Payroll System (FPPS), to process NASA's HR and Payroll transactions and supply all key delivery aspects of its payroll operation functions. The E-Payroll initiative benefits NASA by permitting the Agency to focus on its mission related activities, rather than on administrative payroll functions. Payroll processing costs are reduced through economies of scale and avoiding the cost of duplicative capital system modernization activities. The initiative also promotes standardization of business processes and practices as well as unified service delivery.

## E-Travel (Managing Partner General Services Administration (GSA)) FY 2017 Benefits

NASA completed migration of its travel services to E-Gov Travel Service 2 (ETS2) - Concur Government Edition (CGE) (formerly HP Enterprise Services (FedTraveler)). Completing this migration after implementation the summer of 2014 has allowed NASA to provide more efficient and effective travel management services. ETS2 is a streamlined, adaptable world-class travel management service that continually applies commercial best practices to realize travel efficiencies and deliver a transparent, accountable, and sustainable service that yields exceptional customer satisfaction.

ETS2 builds on the success of the first generation ETS, and will continue to take advantage of advances to help the government further consolidate online travel booking services and expense management platforms, driving additional cost savings and efficiencies while delivering a transparent service for improved accountability and reduced waste. ETS2 serves as the gateway to optimize the Government's scale and full market leverage to lower travel costs. ETS has served as the backbone of GSA's managed travel programs, providing access to air, car and lodging, as well as the foundation for implementing a shared service for civilian agency travel management.

ETS2's new benefits and features include:

- Improved usability and optimized online travel planning;
- Increased navigation and ease-of-use, enabling informed cost and sustainability decisions at point-of-sale; and
- Strengthened operational environment, improving management by adopting commercial best practices in software development, data transparency and improved security controls.

ETS2 will enable the government to further consolidate travel services, platforms, and channels, improve the leverage of government travel spending, increase transparency for improved accountability, and reduce waste. This directly aligns and supports the recent OMB Memo M-12-12 regarding *Promoting Efficient Spending to Support Agency Operations* with respect to travel.

## Integrated Acquisition Environment (Managing Partner GSA) FY 2017 Benefits

The Integrated Acquisition Environment (IAE) initiative is designed to streamline the process of reporting on subcontracting plans and provide agencies with access to analytical data on subcontracting performance. Use of the IAE common services allows agencies to focus on agency-specific needs such as strategy, operations, and management while leveraging shared services for common functions.

Furthermore, use of a government-wide business focused service environment reduces funding and resources for technical services and support for acquisition systems originally housed by individual agencies.

IAE facilitates and supports cost-effective acquisition of goods and services by agencies. The IAE initiative provides common acquisition functions and shared services that benefit all agencies, such as the maintenance of information about business-partner organizations (e.g., banking, certifications, business types, capabilities, performance). IAE provides benefits to the government and business-partner organizations by improving cross-agency coordination that helps to improve the government's buying power, while providing business partners maximum visibility and transparency into the process. IAE provides various services, tools, and capabilities that can be leveraged by the acquisition community including buyers, sellers, and the public to conduct business across the federal government space.

Government buyers can:

- Search for commercial and government sources;
- Post synopses and solicitations;
- Securely post sensitive solicitation documents;
- Access reports on vendors' performance;
- Retrieve vendor data validated by Small Business Administration (SBA) and Internal Revenue Service (IRS);
- Identify excluded parties; and
- Report contract awards.

Business suppliers can:

- Search business opportunities by product, service, agency, or location;
- Receive e-mail notification of solicitations based on specific criteria;
- Register to do business with the Federal Government;
- Enter representations and certifications one time;
- Revalidate registration data annually; and
- Report subcontracting accomplishments.

Citizens can:

- Retrieve data on contract awards;
- Track federal spending;
- Search to find registered businesses; and
- Monitor business opportunities.

Through adoption of the tools and services provided by IAE, NASA improves its ability to make informed and efficient purchasing decisions and allows it to replace manual processes. If NASA did not use IAE systems, the Agency would need to build and maintain separate systems to record vendor and contract information, and to post procurement opportunities. Agency purchasing officials would not have access to databases of important information from other agencies on vendor performance and could not use systems to replace paper-based and labor-intensive work efforts.

### Integrated Acquisition Environment – Loans and Grants FY 2017 Benefits

All agencies participating in the posting and/or awarding of Contracts and Grants & Loans are required by the Federal Funding Accountability and Transparency Act (FFATA) of 2006 as well as the American Recovery and Reinvestment Act of 2009 (ARRA) reporting requirements to disclose award information on a publicly accessible Web site. FFATA requires OMB to lead the development of a single, searchable Web site through which the public can readily access information about grants and contracts provided by Federal government agencies[1].

Based on the recommendations of the Transparency Act Taskforce, the Web site leverages functionality provided by the Integrated Acquisition Environment (IAE) initiative to provide Data Universal Numbering System (DUNS) numbers as the unique identifier. An existing IAE Dun and Bradstreet (D&B) transaction-based contract for the contract community was expanded to provide government-wide D&B services for the Grants & Loans community. These services include parent linkage, help desk support, world database lookup, business validation and linkage monitoring, matching services, as well as the use of DUNS numbers. The enterprise D&B contract provides substantial savings to the participating agencies over their previous agency transaction-based D&B contracts.

On December 14, 2007, OMB launched www.USASpending.gov to meet FFATA statutory requirements, ahead of schedule. Since that launch, OMB has and will continue to work with agencies to improve the quality, timeliness, and accuracy of their data submissions and has released a series of enhancements to the site. USASpending.gov complements other Web sites providing the public Federal program performance information (e.g., USA.gov, Results.gov, and ExpectMore.gov).

USASpending.gov provides:

- The name of the entity receiving the award;
- The amount of the award;
- Information on the award including transaction type, funding agency, etc.;
- The location of the entity receiving the award; and
- A unique identifier of the entity receiving the award.

All agencies participating in the posting and/or awarding of Contracts and Grants & Loans are required by the FFATA as well as the American Recovery and Reinvestment Act of 2009 (ARRA) reporting requirements to disclose award information on a publicly accessible Web site. Cross-government cooperation with OMB's Integrated Acquisition Environment initiative allows agencies and contributing bureaus to meet the requirements of the FFATA by assigning a unique identifier, determining corporate hierarchy, and validating and cleaning up incorrect or incomplete data.

The FY 2014 funding requirements as it relates to the IAE – Loans and Grants funding line supports the FFATA for the relationship with D&B and DUNS support services. In addition to provision of DUNS numbers, D&B is now providing business and linkage data seamlessly, and the business arrangement

[1] More information on the development of this Web site can be found at: http://www.federalspending.gov.

supports the quality of data by real-time updates. NASA and other agencies will leverage the linkages to corporate organizational rollups based on parental and subsidiary relationships.

## LINES OF BUSINESS

### Financial Management Lines of Business (FMLoB) (Managing Partners Department of Energy (DOE) and Department of Labor (DOL)) FY 2017 Benefits

Treasury's Office of Financial Innovation and Transformation (FIT) served as Managing Partner and the Program Management Office (PMO) for the Financial Management Lines of Business (FMLoB). In accordance with OMB's guidance on shared services (the Federal IT Shared Services Strategy), the Treasury's FIT will lead efforts to transform Federal financial management, reduce costs, increase transparency, and improve delivery of agencies' missions by operating at scale, relying on common standards, shared services, and using state-of-the-art technology. Under the guidance of the CFOC and COFAR, partner agencies will work with the FMLoB's support to standardize core financial business processes (including financial assistance) and data elements across the Federal Government to provide: (1) reliable and accessible financial data to the public; (2) adequate training and development resources to agency workforces; and (3) strong oversight of Federal programs using tools such as the Single Audit. The FMLoB will also play a role in implementing OMB's Memorandum M-13-08, *Improving Financial Systems Through Shared Services*. NASA benefits from the FM LoB because it provides a forum in which federal agencies can share information and weigh pros and cons of various initiatives (for example, shared services).

### Human Resources Management LoB (HR LoB) (Managing Partner OPM) FY 2017 Benefits

The Human Resources Management Lines of Business (HR LoB) vision is to create government-wide, modern, cost-effective, standardized, and interoperable HR solutions to provide common core functionality to support the strategic management of Human Resources through the establishment of Shared Service Centers (SSCs). Driven from a business perspective, the solutions will address distinct business improvements enhancing the government's performance of HR and payroll services in support of agency missions delivering services to citizens. The HR LoB concept of operations calls for agencies to receive core services from an HR LoB provider. These core services are defined as personnel action processing, compensation management (payroll) and benefits management. Leveraging shared services solutions will allow the HR LoB to significantly improve HR and payroll service delivery, save taxpayer dollars, and reduce administrative burdens.

NASA works in partnership with one of the approved service providers, the Department of Interior's National Business Center. Through this partnership, NASA shares and receives "best-in-class" HR solutions. The National Business Center delivers NASA-developed solutions to their customer agencies, enabling improved efficiencies and system integrations at a fraction of the cost and delivery time than similar solutions could have been produced by National Business Center. NASA achieves the benefits of "best-in-class" HR solutions through implementation and integration of National Business Center and NASA-developed HR solutions. NASA's participation in HR LoB provides the Agency opportunities to implement modern HR solutions and benefit from best practices government-wide strategic HR management. NASA participates in the ongoing development of a 10-year Federal Human Resources Strategic Plan with the HR LoB managing partner (OPM) and member agencies.

### Geospatial LoB (Managing Partner DOL) FY 2017 Benefits

The Geospatial LoB will better serve the agencies' missions and the Nation's interests developing a more strategic, coordinated, and leveraged approach to producing, maintaining, and using geospatial data and services across the Federal government. Specific goals of the Geospatial LoB include establishing a collaborative governance mechanism, coordinating a government-wide planning and investment strategy, and optimizing and standardizing geospatial data and services.

Contributing agencies and bureaus will receive value from the development of the LoB primarily through improved business performance and cost savings. Enhanced governance processes, improved business planning and investment strategies, and optimization and standardization of geospatial business data and services will produce the following results:

- Collaborative management of geospatial investments will be made more adaptable, proactive and inclusive;
- Enterprise business needs and Agency core mission requirements will be identified, planned, budgeted, and exploited in a geospatial context;
- Long-term costs of geo-information delivery and access will be reduced while minimizing duplicative development efforts;
- Effective, yet less costly commercial off the shelf systems and contractual business support operations will replace legacy geospatial applications; and
- Business processes will be optimized and knowledge management capabilities will exist for locating geospatial data and obtaining services.

As a science agency, the work of NASA's science and mission professionals is inherently different from duties and functions performed by operational agencies. These differences lead NASA to organize and manage data to best facilitate science activities rather than a central focus of data dissemination. Scientific inquiry often leads scientist to use different schemas for analyzing data and information produced from remote sensing data (e.g. a common grid or projection). NASA will continue to apply the elements of Federal Geographic Data Committee standards where these are appropriate. In FY 2008, NASA signed an MOU with the Department of Labor to continue its active participation in the Geospatial LoB.

### Budget Formulation and Execution LoB (BFELoB) (Managing Partner Education) FY 2017 Benefits

The Budget Formulation and Execution LoB (BFELoB) provides significant benefits to NASA and other partner agencies by encouraging best practices crossing all aspects of Federal budgeting – from budget formulation and execution to performance to human capital needs. To benefit all agencies, BFELoB continues to support the idea of shared service budget systems. As NASA currently has its own budgeting tools, the Agency has not chosen to move to a new budget system; however, a shared service budget system is an option moving forward.

BFELoB's "MAX Federal Community," a secure government-only collaborative Web site, provides significant benefits for collaboration across and within agencies, as well as knowledge management. The Community site is commonly used for sharing information, collaboratively drafting documents (including the direct editing of documents posted on the site).

## FY 2015 Operating Plan Crosswalk to FY 2017 Budget Structure

| | | |
|---|---|---|
| **NASA** | **18,010.2** | **18,010.2** |
| **SCIENCE** | **5,243.0** | **5,243.0** |
| Earth Science | 1,784.1 | 1,784.1 |
| Earth Science Research | 453.2 | 453.2 |
| Earth Systematic Missions | 827.3 | 827.3 |
| Ice, Cloud, and Land Elevation Satellite - 2 | 126.5 | 126.5 |
| **Soil Moisture Active and Passive** | **63.1** → | |
| GRACE FO | 84.7 | 84.7 |
| Other Missions and Data Analysis | 553.1 | 616.2 |
| OMDA - Earth Systematic Missions Projects | | 553.1 |
| **Soil Moisture Active and Passive** | | → **63.1** |
| Earth Science Pathfinder | 223.8 | 223.8 |
| Earth Science Multi-Mission Operations | 179.7 | 179.7 |
| Earth Science Technology | 59.7 | 59.7 |
| Applied Sciences: Pathways | 40.4 | 40.4 |
| Planetary Science | 1,446.7 | 1,446.7 |
| Astrophysics | 730.7 | 730.7 |
| Astrophysics Research | 159.7 | 201.7 |
| Astrophysics Research & Analysis | 71.1 | 71.1 |
| Balloon Project | 38.0 | 38.0 |
| Other Missions & Data Analysis | 50.6 | 50.6 |
| **SMD STEM Activities** | | → **42.0** |
| Cosmic Origins | 201.0 | 201.0 |
| Physics of the Cosmos: Other Missions & Data Analysis | 104.1 | 104.1 |
| Exoplanet Exploration | 100.6 | 100.6 |
| Astrophysics Explorer | 123.3 | 123.3 |
| **Science Education & Public Outreach** | **42.0** → | |
| James Webb Space Telescope | 645.4 | 645.4 |
| Heliophysics | 636.1 | 636.1 |
| Heliophysics Research | 192.0 | 192.0 |
| Living With a Star | 263.5 | 263.5 |
| Solar Terrestrial Probes | 70.6 | 70.6 |
| **Magnetospheric Multiscale (MMS)** | **52.4** → | |
| Other Missions & Data Analysis | 18.2 | 18.2 |
| OMDA - Solar Terrestrial Probes Projects | | |
| **Magnetospheric Multiscale (MMS)** | | → **52.4** |
| Heliophysics Explorer | 110.0 | 110.0 |

# COMPARABILITY ADJUSTMENT TABLES

| | | |
|---|---|---|
| **AERONAUTICS** | **642.0** | **642.0** |
| **SPACE TECHNOLOGY** | **600.3** | **600.3** |
| **EXPLORATION** | **4,347.7** | **3,542.7** |
| Human Exploration Capabilities | 3,211.5 | 3,211.5 |
| Orion Multi-Purpose Crew Vehicle: Crew Vehicle Dev. | 1,190.2 | 1,190.2 |
| Space Launch System | 2,021.4 | 2,021.4 |
| **Commercial Spaceflight: Commercial Crew** | **805.0** | |
| Exploration Research & Development | 331.2 | 331.2 |
| **SPACE OPERATIONS** | **3,820.5** | **4,625.5** |
| Space Shuttle | 7.7 | 7.7 |
| International Space Station | 2,973.8 | 1,524.8 |
| International Space Station Program | 2,973.8 | 1,524.8 |
| ISS Systems Operations & Maintenance | 1,113.0 | 1,113.0 |
| ISS Research | 411.8 | 411.8 |
| Satellite Servicing | | |
| **ISS Crew & Cargo Transportation** | **1,449.0** | |
| Space Transportation | | 2,254.0 |
| **Crew and Cargo Program** | | **1,449.0** |
| **Commercial Crew Program** | | **805.0** |
| Space & Flight Support | 839.0 | 839.0 |
| **EDUCATION** | **119.0** | **119.0** |
| **SAFETY, SECURITY AND MISSION SERVICES** | **2,754.6** | **2,754.6** |
| **CONSTRUCTION & ENVIRONMENTAL COMPLIANCE & REST.** | **446.1** | **446.1** |
| **OFFICE OF INSPECTOR GENERAL** | **37.0** | **37.0** |

**FY 2016 Budget Structure Crosswalk to FY 2017 Budget Structure**

| | | |
|---|---|---|
| **NASA** | **19,285.0** | **19,285.0** |
| **SCIENCE** | **5,589.4** | **5,589.4** |
| Earth Science | 1,921.0 | 1,921.0 |
| Earth Science Research | - | - |
| Earth Systematic Missions | - | - |
| Ice, Cloud, and Land Elevation Satellite - 2 | - | - |
| **Soil Moisture Active and Passive** | **15.9** | |
| GRACE FO | - | - |
| Surface Water and Ocean Topography | - | - |
| Other Missions and Data Analysis | - | - |
| OMDA - ESM Projects | - | - |
| **Soil Moisture Active and Passive** | - | **15.9** |
| Earth Science Pathfinder | - | - |
| Earth Science Multi-Mission Operations | - | - |
| Earth Science Technology | - | - |
| Applied Sciences: Pathways | - | - |
| Planetary Science | 1,631.0 | 1,631.0 |
| Astrophysics | 767.6 | 767.6 |
| Astrophysics Research | - | - |
| Astrophysics Research & Analysis | - | - |
| Balloon Project | - | - |
| Other Missions & Data Analysis | - | - |
| **SMD STEM Activities** | - | **37.0** |
| Cosmic Origins | - | - |
| Physics of the Cosmos: Other Missions & Data Analysis | - | - |
| Exoplanet Exploration | - | - |
| Astrophysics Explorer | - | - |
| **Science Education & Public Outreach** | **37.0** | - |
| James Webb Space Telescope | 620.0 | 620.0 |
| Heliophysics | 649.8 | 649.8 |
| Heliophysics Research | - | - |
| Living With a Star | - | - |
| Solar Terrestrial Probes | - | - |
| **Magnetospheric Multiscale (MMS)** | **30.1** | - |
| Other Missions & Data Analysis | - | - |
| OMDA - Solar Terrestrial Probes Projects | - | - |
| **Magnetospheric Multiscale (MMS)** | - | **30.1** |
| Heliophysics Explorer | - | - |
| **AERONAUTICS** | **640.0** | **640.0** |
| **SPACE TECHNOLOGY** | **686.5** | **686.5** |
| **EXPLORATION** | **4,030.0** | **4,030.0** |
| **SPACE OPERATIONS** | **5,029.2** | **5,029.2** |
| **EDUCATION** | **115.0** | **115.0** |
| **SAFETY, SECURITY AND MISSION SERVICES** | **2,768.6** | **2,768.6** |
| **CONSTRUCTION & ENVIRONMENTAL COMPLIANCE & REST.** | **388.9** | **388.9** |
| **OFFICE OF INSPECTOR GENERAL** | **37.4** | **37.4** |

**The FY 2016 Operating Plan pending finalization at the time of Agency budget roll-out.*

# COST AND SCHEDULE PERFORMANCE SUMMARY

## 2016 MAJOR PROGRAM ANNUAL REPORT (MPAR) SUMMARY

The 2016 Major Program Annual Report (MPAR) is provided to meet the requirements of section 103 of the NASA Authorization Act of 2005 (P.L. 109-155; 42 U.S.C. 16613). The 2016 MPAR consists of this summary and fiscal year (FY) 2017 Congressional Justification pages designated as "Projects in Development," for the projects outlined below. These project pages constitute each project's annual report, or if this is the first year for which it is in reporting, the baseline report. The MPAR summary also includes the confidence level of achieving the commitments, as requested in the Conference Report accompanying the FY 2010 Consolidated Appropriations Act (P.L. 111-117).

## CHANGES IN MPAR COMPOSITION SINCE THE FY 2016 NASA BUDGET ESTIMATES

There is one new project with an estimated lifecycle costs greater than $250 million that received authority to proceed into the development phase since NASA submitted its 2015 MPAR in the FY 2016 NASA Congressional Justification:

- Orion Multi-Purpose Crew Vehicle with a baseline development cost of $6,768.4 million at a joint confidence level of 70 percent.

The 2015 MPAR in the FY 2016 NASA Congressional Justification included three projects (Magnetospheric Multiscale [MMS], Soil Moisture Active Passive [SMAP], and Space Network Ground Segment Sustainment [SGSS]) that are no longer in MPAR reporting. NASA successfully launched the MMS spacecraft on March 12, 2015 and the SMAP spacecraft on January 31, 2015. The SMAP spacecraft launched approximately -6 percent below the baseline development cost due to favorable cost performance while the MMS spacecraft launched approximately 2 percent over the baseline development cost.

As part of the recent SGSS replan evaluation, NASA determined that SGSS is more in line with a sustainment project of the existing Space Network rather than a separate development project. The re-evaluation determined SGSS is a sustainment project since it is maintaining the current Space Network by replacing aging and outdated equipment and systems at the ground terminals. As such, SGSS is a level of effort project that will reported as part of Space Communications Networks.

## CHANGES IN COST AND SCHEDULE ESTIMATES FROM THE 2015 MPAR

Eight projects had no changes in their cost or schedule estimates over the last year. Additionally, two projects (Origins, Spectral Interpretation, Resource Identification, and Security - Regolith Explorer [OSIRIS-REx] and Solar Probe Plus [SPP]) experienced development cost decreases of -10 percent and -1 percent respectively from their baselines. Due to cancellation of the March 2016 launch opportunity, plans for InSight are currently under development.

# COST AND SCHEDULE PERFORMANCE SUMMARY

## MPAR SUMMARY TABLE

Figure 1 provides cost, schedule, and confidence level information for NASA projects currently in development with lifecycle cost estimates of $250 million or more. NASA records the estimated development cost and a key schedule milestone and then measures changes from them. NASA tracks one of several key milestones, listed below, for reporting purposes:

- Launch Readiness Date (LRD);
- Full operational capability (FOC);
- Initial operating capability (IOC); or
- Launch Readiness for Exploration Mission (EM)-1 or EM-2.

As a note for clarification, LRD schedule milestones, as reported here, are not typically the launch dates on the NASA launch manifest, but are the desired launch dates as determined by the payload mission and approved by the NASA Flight Planning Board (FPB). A launch manifest is a dynamic schedule that is affected by real world operational activities conducted by NASA and multiple other entities. It reflects the results of a complex process that requires the coordination and cooperation by multiple users for the use of launch range and launch contractor assets. The launch dates shown on the NASA FPB launch manifest are a mixture of confirmed range dates for missions launching within approximately six months and contractual/planning dates for the missions beyond six months from launch. The NASA FPB launch manifest date is typically earlier than the reported schedule dates reported here, thereby allowing for the operationally driven fluctuations to the launch schedule that may be outside of the Project's control. The NASA FPB launch manifest is updated on a periodic basis throughout the year.

The confidence level (CL) estimates reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Each estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as Joint Confidence Level (JCL) estimates; all other CLs reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Additional explanations for the data in the summary table are provided here:

- James Webb Space Telescope (Webb): Cost Estimate includes Construction of Facilities funds.
- Solar Orbiter Collaboration (SOC): Two instruments are below the $250M life cycle cost (LCC) threshold for JCL. Independent cost and schedule estimates completed by Aerospace and Goddard Space Flight Center (GSFC) Resource Analysis Office with each instrument had confidence levels for cost and schedule that were 70 percent when the start of development was approved (at Key Decision Point [KDP]-C).
- Exploration Ground Systems-Ground Systems Development and Operations Program Office (EGS-GSDO): The 80 percent JCL is inferred from analysis based on FY 2014 President's Budget Request (PBR) including FY 2014 Appropriation changes. JCL analysis was completed prior to the release of the FY 2015 PBR. The ABC is informed by the 80 percent JCL and adjusted to reflect the FY 2015 PBR budget reduction.
- Due to cancellation of the March 2016 launch opportunity, plans for InSight are currently under development. Potential budget impacts are not well understood at this time and therefore are not reflected in the table below.

# Cost and Schedule Performance Summary

Additional information on the projects shown in the table below can be found in their individual program and project pages in the main body of the Congressional Justification.

### Figure 1: MPAR Summary and Confidence Levels

| Project | Base Year | JCL (%) | Development Cost Estimate ($M) | | Cost Change (%) | Key Milestone | Key Milestone | | Schedule Change (months) |
|---|---|---|---|---|---|---|---|---|---|
| | | | Base | 2016 | | | Base | 2016 | |
| EGS-GSDO* | 2015 | 80 | 1,843.5 | 1,847.1 | 0% | LR for EM-1 | Nov 2018 | Nov 2018 | 0 |
| GRACE-FO | 2015 | 70 | 264.0 | 263.4 | 0% | LRD | Feb 2018 | Feb 2018 | 0 |
| ICESat-2 | 2015 | 70 | 763.7 | 763.7 | 0% | LRD | Jun 2018 | Jun 2018 | 0 |
| ICON | 2015 | 70 | 196.0 | 195.8 | 0% | LRD | Oct 2017 | Oct 2017 | 0 |
| InSight | 2014 | 70 | 541.8 | 541.8 | 0% | LRD | Mar 2016 | TBD | N/A |
| Orion | 2016 | 70 | 6,768.4 | 6,612.0 | -2% | LR for EM-2 | Apr 2023 | Apr 2023 | 0 |
| OSIRIS-REx | 2014 | 70 | 778.6 | 700.4 | -10% | LRD | Oct 2016 | Oct 2016 | 0 |
| SLS | 2015 | 70 | 7,021.4 | 7,021.4 | 0% | LR for EM-1 | Nov 2018 | Nov 2018 | 0 |
| SOC | 2014 | N/A | 376.9 | 320.0 | -15% | LRD | Oct 2018 | Oct 2018 | 0 |
| SPP | 2015 | 70 | 1,055.7 | 1,050.3 | -1% | LRD | Aug 2018 | Aug 2018 | 0 |
| TESS | 2015 | 70 | 323.2 | 296.4 | -8% | LRD | Jun 2018 | Jun 2018 | 0 |
| Webb | 2012 | 66 | 6,197.9 | 6,188.8 | 0% | LRD | Oct 2018 | Oct 2018 | 0 |

**The 80 percent JCL is inferred from analysis based on FY14 President's Budget Request (PBR) including FY14 Appropriation changes. JCL analysis was completed prior to the release of the FY15 PBR. The ABC is informed by the 80 percent JCL and adjusted to reflect the FY15 PBR budget reduction.*

*Final Acceptance Review (FAR) Launch Readiness (LR) Launch Readiness Date (LRD) Exploration Mission (EM)*

National Aeronautics and Space Administration

Report Regarding

**Basic Research for Fiscal Year 2017**

Pursuant to

Section 1008(c) of the America Competes Act (P.L. 110-69)

# BASIC RESEARCH

## BACKGROUND

Section 1008(c) of the American COMPETES Act (P.L. 110-69) directs that each Executive agency shall submit to the Congress each year, together with documents in support of the budget of the President, a report that outlines agency funding for "*high-risk, high-reward*" basic research projects. Specifically, the report shall describe whether a funding goal has been established that: (1) meets fundamental technological or scientific challenges; (2) involves multidisciplinary work; and (3) involves a high degree of novelty. The Act further stipulates that basic research shall be defined in accordance with Office of Management and Budget (OMB) Circular A-11.

The information requested in section 1008(c) is provided herein.

OMB Circular A-11 defines basic research as systematic study directed toward fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific application towards processes or products in mind. Basic research, however, may include activities with broad applications in mind.

## REPORT

The total Fiscal Year (FY) 2017 NASA budget request is $19.0 billion. The NASA Research and Development (R&D) budget consists of 19 percent basic research, 14 percent applied research, and 34 percent development as defined by OMB circular A-11.

Because much of NASA's work revolves around the creation of one-of-a-kind missions, a relatively large portion of its R&D activities involve *high-risk, high-reward* research and development—from basic research through applications and technology development. In addition, NASA is a leader in using innovative research approaches, such as science competitions and prizes, as well as multidisciplinary approaches. However, since the majority of these activities do not fall within the OMB definition of basic research, they are excluded from this report.

NASA conducts basic research under three accounts: (1) Science Investments, (2) the International Space Station (ISS), and (3) Exploration Research.

Based on the FY 2017 budget request, NASA expects that 34 percent of its basic research in FY 2017 will be for *high-risk, high-reward* fundamental, technical, and scientific challenges that are novel and multidisciplinary. NASA is budgeting $1.225 billion for *high-risk, high-reward* basic research.

### Description of Basic Research Activities

(1) Science Investments: NASA conducts basic research in four theme areas:

- Astrophysics: Study of the origin, evolution, and fate of the universe, and the search for exoplanets;
- Earth Science: Study of the Earth, its interior, oceans, atmosphere, and fundamental processes within and interactions among those areas, including long-term climate change;
- Heliophysics: Study of the Sun, its interior, corona, solar wind, and the heliosphere, specifically including interactions with planetary magnetospheres; and

- Planetary Science: Study of the planets, moons, comets, asteroids and other bodies within our own solar system, including their interiors, surfaces, atmospheres, magnetospheres, etc. and their interactions.

Many of NASA's missions are inherently risky when launched on rockets into space and perform missions in the airless, weightless, high-radiation environment of space or near or on the surface of other planets. In addition, like other high-risk research, the outcomes of the research are often far from clear. However, the rewards can also be great. The following are examples of *high-risk, high-reward* science projects:

### Magnetospheric Multiscale (MMS)

Magnetospheric Multiscale (MMS) launched March 12, 2015 and is investigating the Sun's and Earth's magnetic fields including how they connect and disconnect by explosively transferring energy from one to the other in a process known as magnetic reconnection. Reconnection limits the performance of fusion reactors and is the final governor of space weather that affects modern technological systems, such as telecommunications networks, global positioning system navigation, and electrical power grids. Therefore, understanding reconnection has high potential reward. The four identically instrumented MMS spacecraft fly in an adjustable pyramid-like formation that allows them to observe the three-dimensional structure of magnetic reconnection. MMS sensors measure charged particle velocities, as well as electric and magnetic fields, with unprecedented (milliseconds) time resolution and accuracy needed to capture the elusively thin and fast-moving electron diffusion region. In October 2015, the four spacecraft maneuvered into the tightest multi-spacecraft formation ever flown in orbit, just six miles apart, flying in a tetrahedral formation, with each spacecraft at the tip of a four-sided pyramid. This tight formation will allow NASA to achieve the science goals of the mission, enabling returns from the more than one billion dollars invested to date. For more information, go to http://mms.gsfc.nasa.gov.

### Origins, Spectral Interpretation, Resource Identification, and Security - Regolith Explorer (OSIRIS-REx)

Origins, Spectral Interpretation, Resource Identification, and Security - Regolith Explorer (OSIRIS-REx) is scheduled for launch in September or October 2016 and will travel to a near-Earth carbonaceous asteroid named Bennu, study the asteroid in detail, and bring back a sample to Earth. Asteroids are leftovers formed from the cloud of gas and dust—the solar nebula—that collapsed to form our Sun and the planets about 4.5 billion years ago. As such, they contain the original material from the solar nebula, which can tell us about the conditions of our solar system's birth. By sampling Bennu, OSIRIS-REx will be opening a time capsule from the birth of our solar system. The mission will also measure the Yarkovsky effect, a small force caused by the Sun on an asteroid as it absorbs sunlight and re-emits that energy as heat. The small force adds up over time, affecting the asteroid's orbit, but it is uneven due to an asteroid's shape, wobble, surface composition, and rotation. For scientists to predict an Earth-approaching asteroid's path, they must understand how the effect will change its orbit, and OSIRIS-REx will shed light on this important problem. For more information, go to http://www.nasa.gov/mission_pages/osiris-rex.

(2) ISS: NASA's research goals for ISS are driven by the NASA Authorization Act of 2010 and recommendations from the National Research Council. These goals focus on the following areas: human health and exploration, technology development and demonstration, physical sciences research, biology and biotechnology research, earth and space science research, education, and enabling the development of

market driven commercial research and applications in low Earth orbit. For more information, go to http://www.nasa.gov/mission_pages/station/research/index.html.

NASA will be initiating its first GeneLab flight experiments in 2016. Through GeneLab in space biology, and MaterialsLab, CombustionLab, and FluidsLab counterparts in the physical sciences, NASA is experimenting with a new approach to research that is intended to allow greater, more diverse participation in space research than was possible with the historical approach of experiments defined by a single principal investigator. The new approach will begin with the definition of comprehensive experiments by representatives of the research community who will also oversee the execution of the experiment. Following the acquisition of all relevant experimental data, the data will be made available to the community, and competitive awards will be made to scientists to explore and analyze the data. It is expected that through community participation in experiment definition and enhanced access to experimental results under a new Open Science interface, we will see more engagement of the research community in space research, and a greater impact of space research in the progress of science.

(3) Exploration: NASA's Human Research Program (HRP) is dedicated to discovering the best methods and technologies to support safe, productive human space exploration. The major areas of HRP's physiological research include bone health, muscle function, cardiovascular response, sensorimotor systems, immunology, behavioral health, biomedical technology, and space radiation effects. One example of this *high-risk, high-reward* research is in the area of applications of genetics to personalized medicine.

Scott Kelly, returning from a year in orbit in March 2016, is participating in a set of pioneering experiments that are examining his genetics, changes to his genetics, and how they correlate to his health. Personalized medicine is a burgeoning field, particularly in cancer treatment, especially when there are sufficient data available to support studies associated genetic variants with particular conditions or responses. Astronauts present a unique challenge for these association studies because the number of subjects available for the study of genetic factors in space-related medical conditions is inherently low. The work sponsored by HRP to apply genetics to space medicine will need to overcome this statistical challenge, and may serve as a paradigm for applying genomic information to medicine in other situations where the number of subjects is small. For more information, go to http://www.nasa.gov/exploration/humanresearch.

## SUMMARY

The NASA 2017 budget supports an extensive program of *high-risk, high-reward* basic research that is novel, multidisciplinary, and of fundamental scientific or technological interest. NASA expects 34 percent of its basic research to be *high-risk, high-reward*.

# FY 2017 PROPOSED APPROPRIATIONS LANGUAGE

## SCIENCE

For necessary expenses, not otherwise provided for, in the conduct and support of science research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, [$5,589,400,000]*$5,302,500,000*, to remain available until September 30, [2017] *2018*. (Science Appropriations Act, 2016.)

## AERONAUTICS

For necessary expenses, not otherwise provided for, in the conduct and support of aeronautics research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, [$640,000,000], *$634,500,000* to remain available until September 30, [2017] *2018*. (Science Appropriations Act, 2016.)

## SPACE TECHNOLOGY

For necessary expenses, not otherwise provided for, in the conduct and support of space technology research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, [$686,500,000] *$690,600,000*, to remain available until September 30, [2017] *2018*. (Science Appropriations Act, 2016.)

## EXPLORATION

For necessary expenses, not otherwise provided for, in the conduct and support of exploration research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, [$4,030,000,000] *$3,158,077,000*, to remain available until September 30, [2017] *2018*. (Science Appropriations Act, 2016.)

# FY 2017 PROPOSED APPROPRIATIONS LANGUAGE

## SPACE OPERATIONS

For necessary expenses, not otherwise provided for, in the conduct and support of space operations research and development activities, including research, development, operations, support and services; space flight, spacecraft control and communications activities, including operations, production, and services; maintenance and repair, facility planning and design; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance and operation of mission and administrative aircraft, [$5,029,200,000] *$5,081,623,000*, to remain available until September 30, [2017] *2018*. (Science Appropriations Act, 2016.)

## EDUCATION

For necessary expenses, not otherwise provided for, in the conduct and support of aerospace and aeronautical education research and development activities, including research, development, operations, support, and services; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, [$115,000,000] *$100,100,000*, to remain available until September 30, [2017] *2018*. (Science Appropriations Act, 2016.)

## SAFETY, SECURITY, AND MISSION SERVICES

For necessary expenses, not otherwise provided for, in the conduct and support of science, aeronautics, space technology, exploration, space operations and education research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; not to exceed $63,000 for official reception and representation expenses; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, [$2,768,600,000] *$2,836,800,000*, to remain available until September 30, [2017] *2018*. (Science Appropriations Act, 2016.)

## CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

For necessary expenses for construction of facilities including repair, rehabilitation, revitalization, and modification of facilities, construction of new facilities and additions to existing facilities, facility planning and design, and restoration, and acquisition or condemnation of real property, as authorized by law, and environmental compliance and restoration, [$388,900,000] *$419,800,000*, to remain available until September 30, [2021] *2022*: Provided, That proceeds from leases deposited into this account shall be available for a period of 5 years. Provided further, That each annual budget request shall include an annual estimate of gross receipts and collections and proposed use of all funds collected pursuant to section 20145 of title 51, United States Code. (Science Appropriations Act, 2016.)

# FY 2017 PROPOSED APPROPRIATIONS LANGUAGE

## INSPECTOR GENERAL

For necessary expenses of the Office of Inspector General in carrying out the Inspector General Act of 1978, [$37,400,000] *$38,100,000*, of which $500,000 shall remain available until September 30, [2017] 2018. (Science Appropriations Act, 2016.)

## ADMINISTRATIVE PROVISIONS

Funds for any announced prize otherwise authorized shall remain available, without fiscal year limitation, until a prize is claimed or the offer is withdrawn.

Not to exceed 5 percent of any appropriation made available for the current fiscal year for the National Aeronautics and Space Administration in this Act may be transferred between such appropriations, but no such appropriation, except as otherwise specifically provided, shall be increased by more than 10 percent by any such transfers. Balances so transferred shall be merged with and available for the same purposes and the same time period as the appropriations to which transferred. Any transfer pursuant to this provision shall be treated as a reprogramming of funds under section 505 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

The spending plan required by this Act shall be provided by NASA at the theme, program, project, and activity level. The spending plan, as well as any subsequent change of an amount established in that spending plan that meets the notification requirements of section 505 of this Act, shall be treated as a reprogramming under section 505 of this Act and shall not be available for obligation or expenditure except in compliance with the procedures set forth in that section.

The unexpired balances for Commercial Spaceflight Activities contained within the Exploration account may be transferred to the Space Operations account for such activities. Balances so transferred shall be merged with the funds in the Space Operations account and shall be available under the same terms, conditions and period of time as previously appropriated.

For the closeout of all Space Shuttle contracts and associated programs, amounts that have expired but have not been cancelled in the Exploration, Space Operations, Human Space Flight, Space Flight Capabilities, and Exploration Capabilities appropriations accounts shall remain available through fiscal year 2025.

Subsection (g) (‘Sunset’) of Section 20145 of Title 51 (51 U.S.C. § 20145(g)) is hereby deleted in its entirety. (Science Appropriations Act, 2016.)

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| $K | Dollars in thousands |
| $M | Dollars in millions |
| 21CCLC | 21st Century Community Learning Center |
| 21CSLC | 21st Century Space Launch Complex |
| 2MASS | Two Micron All Sky Survey |
| 3U | 3-unit |
| 45SW | 45th Space Wing |
| AA | Ascent Abort Test (HEOMD) |
| AA | Associates of Art (Education) |
| AANAPISI | Asian American and Native American Pacific Islander-Serving Institutions |
| AAVP | Advanced Air Vehicles Program |
| ABC | Agency Baseline Commitment |
| ABoVE | Arctic – Boreal Vulnerability Experiment |
| ACC | Advanced Composites Consortium |
| ACCESS | Advancing Collaborative Connections for Earth System Science |
| ACCESS-II | Alternative Fuel Effects on Contrails and Cruise Emissions II |
| ACE | Advanced Composition Explorer (Heliophysics) |
| ACE-T-1 | Advanced Colloids Experiment-Temperature control-1 |
| ACME | Advanced Combustion via Microgravity Experiments |
| ACRIMSat | Active Cavity Radiometer Irradiance Monitor Satellite |
| ACTE | adaptive compliant trailing-edge technology |
| ADAP | Astrophysics Data Analysis Program |
| ADCAR | Astrophysics Data Curation and Archival Research |
| ADS-B | Automatic Dependent Surveillance-Broadcast |
| ADSM | Astrophysics Decadal Strategic Mission |
| AEDL | Advanced Entry Descent and Landing |
| AES | Advanced Exploration Systems |
| AFO | Altimetry Follow-On |
| AFRC | Armstrong Flight Research Center |
| AFRL | Air Force Research Laboratory |
| AFTA | Astrophysics Focused Telescope Assets |
| AGSM | Advanced Ground Systems Maintenance |
| AIANSI | American Indian and Alaskan Native Serving Institutions |
| AIDA | Asteroid Impact and Deflection Assessment |
| AIM | Aeronomy of Ice in the Mesosphere |
| AirMOSS | Airborne Microwave Observatory of Subcanopy and Subsurface |
| AIRS | Atmospheric Infrared Sounder |
| AIST | Advanced Information Systems Technology |
| AIT | Accident Investigation Team |
| AITS | Agency Information Technology Services |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AITT | Airborne Instrument Technology Transition |
| ALI | Advanced Land Imager |
| AMMOS | Advanced Multi-Mission Operations System |
| AMO | Agency Management and Operations |
| AMOC | Atlantic Meridional Overturning Circulation |
| AMR | Advanced Microwave Radiometer |
| AMSIR-E | Advanced Microwave Scanning Radiometer - Earth Observing System |
| AMSU | Advanced Microwave Sounding Unit |
| AO | Announcement of Opportunity |
| AOSP | Airspace Operations and Safety Program |
| APEX-05 | Advanced Plant Experiments 5 |
| APH | Advanced Plant Habitat |
| APL | Applied Physics Laboratory |
| APMC | Agency Project Management Council |
| AR | Advanced Radiometer |
| ARC | Ames Research Center |
| ARCD | Aerospace Research and Career Development |
| ARM | Asteroid Redirect Mission |
| ARMD | Aeronautics Research Mission Directorate |
| ARRA | American Recovery and Reinvestment Act |
| ARRM | Asteroid Redirect Robotic Mission |
| ARSET | Applied Remote Sensing Training |
| ARTEMIS | Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun |
| ASAP | Aerospace Safety Advisory Panel |
| ASCENDS | Active Sensing of CO2 Emissions over Nights, Days, and Seasons |
| ASDM | Astrophysics Decadal Strategic Mission |
| ASI | Agenzia Spaziale Italiana |
| ASIAS | Aviation Safety Information and Sharing System |
| ASPERA | Analyzer of Space Plasmas and Energetic Atoms |
| ASTER | Advanced Spaceborne Thermal Emission and Reflection Radiometer |
| ATCC | A-Complex Test Control Center |
| ATD | ATM Technology Demonstrations |
| ATLAS | Advanced Topographic Laser Altimeter System |
| ATM | Air Traffic Management |
| ATTREX | Airborne Tropical TRopopause Experiment |
| AU | Astronomical Unit |
| AURA | Association of Universities for Research in Astronomy |
| BAA | Broad Agency Announcement |
| BARREL | Balloon Array for Radiation-belt Relativistic Electron Losses |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| BASS-M | Burning and Suppression of Solids – Milliken |
| BEAM | Bigelow Expandable Activity Module |
| BFELoB | Budget Formulation & Execution Lines of Business |
| BPS | Biological and Physical Sciences |
| BWG | Beam Wave Guide |
| C/NOFS | Communication/Navigation Outage Forecast System |
| CAL | Cold Atom Laboratory |
| CALIPSO | Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations |
| CAMMEE | Committee on Aerospace Medicine and the Medicine of Extreme Environments |
| CAP | Cross-Agency Priority |
| CARVE | Carbon in Arctic Reservoirs Vulnerability Experiment |
| CAS | Convergent Aeronautics Solutions |
| CASIS | Center for the Advancement of Science in Space |
| CAST | Commercial Aviation Safety Team |
| CATALYST | Cargo Transportation and Landing by Soft Touchdown |
| CATS | Cloud Aerosol Transport System |
| CBT | Computer-Based Training |
| CC/TS | Community Colleges and Technical Schools |
| CCAFS | Cape Canaveral Air Force Station |
| CCD | charge-coupled device |
| CCDev2 | Commercial Crew Development Round 2 |
| CCiCap | Commercial Crew Integrated Capability |
| CCM | Camera Control Module |
| CCMC | Community Coordinated Modeling Center |
| CCP | Commercial Crew Program |
| CCtCap | Commercial Crew transportation Capabilities |
| CDC | Centers for Disease Control |
| CDI | Climate Data Initiative |
| CDM | Continuous Diagnostic Mitigation |
| CDR | Critical Design Review |
| CDS | Cascade Distiller System |
| CDTI | Center for the Development of Industrial Technology |
| CECR | Construction and Environmental Compliance and Restoration |
| CEQA | California Environmental Quality Act |
| CERES | Clouds and the Earth's Radiant Energy Systems |
| CFD | Computational Fluid Dynamics |
| CFE | Capillary Flow Experiment |
| CFOC | Chief Financial Officer's Council |
| CGE | Concur Government Edition |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| CHAMPS™ | CubeSat High-Impulse Adaptable Modular Propulsion System™ |
| CHS | Crew Health and Safety |
| CIBER | Cosmic Infrared Background ExpeRiment |
| CIF | Center Innovation Fund |
| CINDI | Coupled Ion-Neutral Dynamics Investigations |
| CIR | Combustion Integrated Rack |
| CIRs | co-rotating interaction regions |
| CL | confidence level |
| CLARREO | Climate Absolute Radiance and Refractivity Observatory |
| CM | Crew Module |
| CMA | Crew Module Adapter |
| CMC | ceramic matrix composites |
| CME | Coronal Mass Ejection |
| CMO | Center Management and Operations |
| CMS | Carbon Monitoring System |
| CNES | Centre National d'Etudes' Spatiales |
| CoECI | Center of Excellence for Collaborative Innovation |
| CoF | Construction of Facilities |
| COFAR | Council on Financial Assistance Reform |
| Comet C-S | Comet Churyumov-Gerasimenko |
| COR | Cosmic Origins |
| CORAL | COral Reef Airborne Laboratory |
| COSI | Compton Spectrometer and Imager |
| CoSTEM | committee on science, technology, engineering, and mathematics |
| COTS | Commercial Off-The-Shelf |
| CPC | Certification Products Contracts |
| CPOD | CubeSat Proximity Operations Demonstration |
| CREAM | Cosmic Ray Energetics and Mass |
| CRP | Commercialization Readiness Program |
| CRS | Commercial Resupply Services |
| CRT | Climate Resilience Toolkit |
| CRV | current replacement value |
| CSA | Canadian Space Agency |
| CSBF | Columbia Scientific Balloon Facility |
| CSC | Computer Sciences Corporation |
| CSL | Belgian Centre Spatial de Liège |
| CSO | Communications Services Office |
| CSTD | Crosscutting Space Technology Development |
| CTS | Crew Transportation System |
| CYGNSS | Cyclone Global Navigation Satellite System |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| D&B | Dun and Bradstreet |
| DAAC | Distributed Active Archive Center |
| DAEP | DSN Aperture Enhancement Project |
| DART | Double Asteroid Redirection Test |
| DATA | Digital Accountability and Transparency Act |
| DAVINCI | Deep Atmosphere Venus Investigation of Noble Gases, Chemistry, and Imaging |
| DCAA | Defense Contract Audit Agency |
| DCT | Development to Certification Timeline |
| DEP | distributed electric propulsion |
| DESDynI | Deformation, Ecosystem Structure, and Dynamics of Ice |
| DHS | Department of Homeland Security |
| DISCOVER-AQ | Deriving Information on Surface Conditions from COlumn and VERtically Resolved Observations Relevant to Air Quality |
| DLP | Data Loss Prevention |
| DLR | German Aerospace Center |
| DLS | Deployable Launch System |
| DNA | Deoxyribonucleic acid |
| DoD | Department of Defense |
| DOE | Department of Energy |
| DOI | Department of Interior |
| DOJ | Department of Justice |
| DOL | Department of Labor |
| DORIS | Doppler Orbitography and Radiopositioning Integrated by Satellite |
| DPMC | Directorate Program Management Council |
| DPR | Dual-frequency Precipitation Radar |
| DRE | discrete roughness elements |
| DRIVE | Diversify, Realize, Integrate, Venture, Educate |
| DSAC | Deep Space Atomic Clock |
| DSCC | Deep Space Communications Complex |
| DSCOVR | Deep Space Climate Observatory |
| DSI | Deutsches SOFIA Institute |
| DSN | Deep Space Network |
| DSOC | Deep Space Optical Communication |
| DSS | Deep Space Station |
| DSX | Demonstration and Space Experiments |
| DTN | Disruption Tolerant Networking |
| DUNS | Data Universal Numbering System |
| EB | existing building |
| ECAST | Expert and Citizen Assessment of Science and Technology |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ECOSTRESS | Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station |
| ECR | Environmental Compliance and Restoration |
| eCryo | Evolvable Cryogenics |
| EDL | Entry, Descent, and Landing |
| EFT | Exploration Flight Test |
| EGS | Exploration Ground Systems |
| EHRI | Enterprise HR Integration |
| EHRS | Electronic Health Records System |
| EICC | EPSCoR Interagency Coordinating Committee |
| ELM | Electrical Model |
| ELV | Expendable Launch Vehicle |
| ELVIS | Expendable Launch Vehicle Integrated Support |
| EM | Exploration Mission |
| EO-1 | Earth Observing 1 |
| EONS | Education Opportunities in NASA STEM |
| EONS | Educational Opportunities in NASA STEM |
| eOPF | electronic Official Personnel Folder |
| EOS | Earth Observation Systems |
| EOSDIS | Earth Observing System Data and Information System |
| EPA | Environmental Protection Agency |
| EPIC | Earth Poly-Chromatic Imaging Camera |
| EPSCoR | Experimental Project To Stimulate Competitive Research |
| EQM | Engineering Qualification Model |
| ERA | Environmentally Responsible Aviation |
| ERBS | Earth Radiation Budget Science |
| ERD | Exploration Research and Development |
| EROS | Earth Resources Observation and Science |
| ESA | European Space Agency |
| ESDN | Edison Demonstration of Smallsat Networks |
| ESM | Earth Systematic Missions (Earth Science) |
| ESM | European Service Module (HEOMD) |
| ESSP | Earth System Science Pathfinder |
| E-STA | ESM Structural Test Article |
| ESTEEM | Earth Systems, Technology and Energy Education for MUREP |
| ESTO | Earth Science Technology Office |
| ESTP | Earth Science Technology Program |
| ETA | engineering test article |
| ETB | Engineering Testbed |
| ETD | Exploration Technology Development |
| ETS2 | E-Gov Travel Service 2 |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| EUL | Enhanced Use Leasing |
| EUMETSAT | European Organisation for the Exploitation of Meterological Satellites |
| EUS | Exploration Upper Stage |
| EVA | extravehicular activity |
| EVI | Earth Venture Instruments |
| EVM | Earth Venture small Missions |
| EVS | Earth Venture Suborbital |
| EX | Explorers |
| FAA | Federal Aviation Administration |
| FAR | Federal Acquisition Regulation |
| FDC | Flight Demonstrations and Capabilities |
| FDMS | Federal Docket Management System |
| FFATA | Federal Funding Accountability and Transparency Act |
| FFI | Forsvarets Forskning Institute |
| FGS | Fine Guidance Sensor |
| FIRST | For Inspiration and Recognition of Science and Technology |
| FIT | Financial Innovation and Transformation |
| FMLoB | Financial Management Lines of Business |
| FO | Follow-On |
| FOALS | Fuel Optimal and Accurate Landing System |
| FOC | full operational capability |
| FPB | Flight Planning Board |
| FPI | Fast Plasma Investigation |
| FPPS | Federal Personnel and Payroll System |
| FRR | Flight Readiness Review |
| FY | fiscal year |
| GALEX | Galaxy Evolution Explorer |
| GCD | Game Changing Development |
| GCIS | Global Change Information System |
| GCOM-W1 | Global Change Observation Mission 1st - Water |
| GCR | Grand Challenge Research |
| GEDI | Global Ecosystem Dynamics Investigation |
| GEMS | Gravity and Extreme Magnetism |
| GEO-CAPE | GEOstationary Coastal and Air Pollution Events |
| GEOGLAM | Global Agricultural Monitoring |
| GeoSTAR | Geostationary Thinned Aperture Radiometer |
| GFAST | Ground Flight Application Software Team |
| GFZ | German Research Centre for Geosciences |
| GHe | gaseous helium |
| GIS | Geographic Information System |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| GLOBE | Global Learning and Observations to Benefit the Environment |
| GMAO | Global Modeling and Assimilation Office |
| GMI | GPM Microwave Imager |
| GN | gaseous nitrogen |
| GNC | Guidance, Navigation, and Control |
| GO | Guest Observer |
| GOES-R | Geostationary Operational Environmental Satellite-R |
| GOLD | Global-scale Observations of the Limb and Disk |
| GPIM | Green Propellant Infusion Mission |
| GPM | Global Precipitation Measurement |
| GPS | Global Positioning System |
| GPSP | Global Positioning System-Payload |
| GRACE | Gravity Recovery and Climate Experiment |
| GRACE-FO | Gravity Recovery and Climate Experiment Follow-On |
| GRAIL | Gravity Recovery and Interior Laboratory |
| GRC | Glenn Research Center |
| GRC-PBS | Glenn Research Center Plum Brook Station |
| GRIFEX | GEO-CAPE Readout Integrated Circuit Experiment |
| GRIPS | Gamma-Ray Imager/Polarimeter for Solar Flares |
| GrOAWL | Green OAWL |
| GSA | General Services Administration |
| GSDO | Ground Systems Development and Operations |
| GSE | Ground Support Equipment |
| GSFC | Goddard Space Flight Center |
| GSI | Ground Systems Implementation |
| GSLV | Geosynchronous Satellite Launch Vehicle |
| GSRT | GSFC System Review Team |
| HAWC+ | High-resolution Airborne Wideband Camera |
| HBCU | Historically Black Colleges and Universities |
| HCl | hydrochloric acid |
| HECC | High End Computing Capability |
| HEEET | Heat shield for Extreme Entry Environment Technology |
| HEO | Human Exploration and Operations |
| HEOMD | Human Exploration and Operations Mission Directorate |
| HERA | Human Exploration Research Analog |
| HF | High Frequency |
| HFC | hydrofluorocarbon |
| HHS | Department of Health and Human Services |
| HIAD | Hypersonic Inflatable Aeroshell Decelerator |
| HICO | Hyperspectral Imager for the Coastal Ocean |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| HIS | Heavy Ion Sensor |
| HITL | human-in-the-loop |
| HMI | Helioseismic and Magnetic Imager |
| HMTA | Health and Medical Technical Authority |
| HMV | Heavy Maintenance Visit |
| HP3 | Heat Flow and Physical Properties Package |
| HPA | high-pressure air |
| HQ | Headquarters |
| HR | Human resources |
| HRP | Human Research Program |
| HS-3 | Hurricane and Severe Storm Sentinel |
| HSFO | Human Space Flight Operations |
| HSI | Hispanic-Serving Institutions |
| HT | Hypersonics Technology |
| HTV | H-II Transfer Vehicle |
| HVAC | Heating, Ventilation, and Air Conditioning |
| HWB | Hybrid Wing Body |
| HyspIRI | Hyperspectral Infrared Imager |
| I&T | Integration & Test |
| I3P | Infrastructure Integration Program |
| IAA | Interagency Agreement |
| IADS | Integrated Arrival/Departure/Surface |
| IAE | Integrated Acquisition Environment |
| IASP | Integrated Aviation Systems Program |
| IBEX | Interstellar Boundary Explorer |
| IBR | Integrated Baseline Review |
| IC | Institutional Committee |
| ICESat | Ice, Cloud, and land Elevation Satellite |
| ICESat-2 | Ice, Cloud, and land Elevation Satellite-2 |
| ICON | Ionospheric Connection Explorer |
| ICPS | Interim Cryogenic Propulsion Stage |
| ICRP | Independent Comprehensive Review Panel |
| IDIQ | indefinite delivery/indefinite quantity |
| IDS | Intrusion Detection Systems |
| IIP | Instrument Incubator Program |
| ILT | Instructor-Led Training |
| IMBIE | Ice sheet Mass Balance Inter-comparison Exercise |
| IMC | International Mission Contributions |
| IMERG | Integrated Multi-satellite Retrievals for GPM |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| InSight | Interior Exploration using Seismic Investigations, Geodesy and Heat Transport |
| INTA | National Institute of Aerospace Technology |
| InVEST | In-space Validation of Earth Science Technology |
| IOC | initial operating capability |
| IPAO | Independent Program Assessment Office |
| IPCC | Intergovernmental Panel on Climate Change |
| IR | infrared |
| i-RFI | internal-to-NASA request for information |
| IRIS | Interface Region Imaging Spectrograph |
| IRS | Internal Revenue Service |
| IRSA | Infrared Science Archive |
| IRT | Independent Review Team |
| IRTF | InfraRed Telescope Facility |
| ISARA | Integrated Solar Array and Reflectarray Antenna |
| ISAS | Institute of Space and Astronautical Science |
| ISCM | Information Security Continuous Monitoring |
| ISERV | ISS SERVIR Environmental Research and Visualization System |
| ISIM | Integrated Science Instrument Module |
| ISIS | Integrated Science Investigation of the Sun |
| ISRO | Indian Space Research Organisation |
| ISRS | In-Space Robotic Servicing |
| ISRU | in-situ resource utilization |
| ISS | International Space Station |
| IT | information technology |
| ITAR | International Traffic in Arms Regulations |
| ITD | Integrated Technology Demonstration |
| I-trek | I turn research into empowerment and knowledge |
| ITSEC-EDW | IT Security Enterprise Data Warehouse |
| IV&V | Independent Verification and Validation |
| JAXA | Japanese Aerospace Exploration Agency |
| JCL | Joint Confidence Level |
| JEL | jacking, equalizing, and leveling |
| JEM-EF | Japanese Experiment Module – Exposed Facility |
| JHU | Johns Hopkins University |
| JPL | Jet Propulsion Laboratory |
| JPSS | Joint Polar Satellite System |
| JRC | Joint Research Centre |
| JSC | Johnson Space Center |
| JUICE | Jupiter Icy Moons Explorer |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| KaBOOM | Ka-Band Objects Observation and Monitoring |
| KaRIn | Ka-band Radar Interferometer |
| KBOs | Kuiper Belt objects |
| KDP | Key Decision Point |
| KH | Kelvin-Helmholtz |
| KOA | Keck Observatory Archive |
| KSC | Kennedy Space Center |
| kV | kilovolt |
| kW | kilowatt |
| LADEE | Lunar Atmosphere and Dust Environment Explorer |
| LaRC | Langley Research Center |
| LAS | Launch Abort System |
| LBFD | Low Boom Flight Demonstrator |
| LBTI | Large Binocular Telescope Interferometer |
| LC | Launch Complex |
| LCC | life cycle cost |
| LCPSO | Land Cover Project Science Office |
| LDAS | Land Data Assimilation System |
| LDCM | Landsat Data Continuity Mission |
| LDSD | Low Density Supersonic Decelerator |
| LEARN | Leading Edge Aeronautics Research for NASA |
| LED | Light-Emitting Diode |
| LEED | Leadership in Energy and Environmental Design |
| LIDAR | light detection and ranging |
| LIS | Land Information System |
| LISA | Laser Inferferometer Space Antenna |
| LLCD | Lunar Laser Communication Demonstration |
| LMSAL | Lockheed Martin Solar and Astrophysics Laboratory |
| LMSSC | Lockheed Martin Space Systems Company |
| LoB | Lines of Business |
| LOB | Line of Business |
| LOLA | Lunar Orbiter Laser Altimeter |
| LOX | liquid oxygen |
| LRA | Laser Retroreflector Assembly |
| LRCD | Laser Communication Relay Demonstration |
| LRD | Launch Readiness Date |
| LRO | Lunar Reconnaissance Orbiter |
| LRR | Launch Readiness Review |
| LSP | Launch Services Provider |
| Lunar CATALYST | Lunar Cargo Transportation and Landing by Soft Touchdown |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| LVC-DE | Live Virtual Constructive-Distributed Environment |
| LVIS | Land, Vegetation, and Ice Sensor |
| LWS | Living With a Star |
| MAA | MUREP Aerospace Academy |
| MAF | Michoud Assembly Facility |
| MAIANSE | MUREP for American Indian and Alaskan Native STEM Engagement |
| MARS | Mid-Atlantic Regional Spaceport |
| MARSIS | Mars Advanced Radar for Subsurface and Ionospheric Sounding |
| MAV | Mars Ascent Vehicle |
| MAVEN | Mars Atmosphere and Volatile EvolutioN |
| MC3I | MUREP Community College Curriculum Improvement |
| MCC | Mission Control Center |
| MCI | Minority University Research and Education Program Community College Curriculum Improvement |
| MCR | Mission Concept Review |
| MDR | Mission Definition Review |
| MDSCC | Madrid Deep Space Communications Complex |
| MEaSUREs | Making Earth System data records for Use in Research Environments |
| MEDLI | Mars Entry, Descent, and Landing Instrumentation |
| MEI | Minority University Research and Education Program Educator Institute |
| MEI | MUREP Educator Institute |
| MER | Mars Exploration Rover |
| MERLIN | Mesoscale Eastern Range Lightning Information Network |
| MERRA | Modern Era Retrospective-analysis for Research and Applications |
| MESSENGER | MErcury Surface, Space ENvironment, GEochemistry, and Ranging |
| MIDEX | Medium Explorers |
| MIRI | Mid-Infrared Instrument |
| MIRO | MUREP Institutional Research Opportunity |
| MIs | minority institutions |
| MISR | Multi-angle Imaging SpectroRadiometer |
| MIT | Massachusetts Institute of Technology |
| ML | Mobile Launcher |
| MLCC | multi-layer ceramic capacitor |
| MLS | Microwave Limb Sounder |
| MLTI | mesosphere-lower thermosphere-ionosphere |
| MMO | Multi-Mission Operations |
| MMOD | MicroMeteoroid and Orbital Debris |
| MMS | Magnetospheric Multiscale |
| MMT | Mission Management Team |
| MO | Mission of Opportunity |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| MO&I | Mission Operations and Integration |
| MODIS | Aqua Moderate Resolution Imaging Spectroradiometer |
| MOMA-MS | Mars Organic Molecule Analyzer Mass Spectrometer |
| MOO | Multi-Mission Operations |
| MOPITT | Measurements Of Pollution In The Troposphere |
| MOPS | Minimum Operating Performance Standards |
| MOXIE | Mars Oxygen ISRU Experiment |
| MPAR | Major Program Annual Report |
| MPPF | Multi-Payload Processing Facility |
| MPRAT | Mission Profile Risk Assessment Test |
| MRO | Mars Reconnaissance Orbiter |
| MRR | Mission Readiness Review |
| MSE | MUREP STEM Engagement |
| MSFC | Marshall Space Flight Center |
| MSI | Minority-Serving Institutions |
| MSL | Measurement Systems Laboratory |
| mths | months |
| MUREP | Minority University Research and Education Program |
| MUSES | Multi-User System for Earth Sensing |
| MUSS | multi-user systems support |
| N/A | Not Applicable |
| NAC | National Agency Check |
| NAH | New Aviation Horizons |
| NAS | National Airspace System |
| NASA | National Aeronautics and Space Administration |
| NAVO | NASA Astronomical Virtual Observatory |
| NCCS | NASA Center for Climate Simulations |
| NCRP | National Council on Radiation Protection |
| NEACC | NASA Enterprise Applications Competency Center |
| NED | NASA Extragalactic Database |
| NEEMO | NASA Extreme Environment Mission Operations |
| NEN | Near Earth Network |
| NEO | near Earth object |
| NEOCam | Near Earth Object Camera |
| NEOO | Near Earth Object Observations |
| NEOWISE | Near Earth Object Wide-field Infrared Survey Explorer |
| NEPA | National Environmental Policy Act |
| NESC | NASA Engineering and Safety Center |
| NextGen | Next Generation Air Transportation System |
| NextSTEP | Next Space Technologies for Exploration Partnerships |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| NFPA | National Fire Protection Association |
| NGAS | Northrop Grumman Aerospace Systems |
| NHPA | National Historic Preservation Act |
| NIAC | NASA Innovative Advanced Concepts |
| NICER | Neutron-star Interior Composition Explorer |
| NIFS | NASA Internship, Fellowship, and Scholarship |
| NIH | National Institutes of Health |
| NIRCam | Near Infrared Camera |
| NIRISS | Near Infrared Imager and Slitless Spectrograph |
| NIRSpec | Near Infrared Spectrograph |
| NISAR | NASA-ISRO Synthetic Aperture Radar |
| NISN | NASA Integrated Services Network |
| NIST | National Institute of Standards and Technology |
| NISTAR | NIST Advanced Radiometer |
| NLCs | noctilucent clouds |
| NLS | NASA Launch Services |
| NMO | NASA Management Office |
| NOAA | National Oceanic and Atmospheric Administration |
| NODES | Network & Operation Demonstration Satellite |
| NOx | mono nitrogen oxide |
| NPP | National Polar-orbiting Partnership |
| NRA | NASA Research Announcement |
| NRC | National Research Council |
| NREP | NanoRacks Exposure Platform |
| NRPTA | National Rocket Propulsion Test Alliance |
| NSBRI | National Space Biomedical Research Institute |
| NSC | NASA Safety Center |
| NSF | National Science Foundation |
| NSSC | NASA Shared Services Center |
| NSSDC | National Space Science Data Center |
| NSTP PPD | National Space Policy Launch Infrastructure and Modernization Plan |
| NTL | NASA Tournament Lab |
| NuSTAR | Nuclear Spectroscopic Telescope Array |
| O&M | operations and maintenance |
| OA | Orbital ATK |
| OAWL | Optical Autocovariance Wind Lidar |
| OCAMS | OSIRIS-REx Camera Suite |
| OCHMO | Office of Chief Health Medical Officer |
| OCO | Orbiting Carbon Observatory |
| OCSD | Optical Communications and Sensor Demonstration |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| OCT | Office of the Chief Technologist |
| OE | Office of Education |
| OGLE | Optical Gravitational Lensing Experiment |
| OI | Office of Investigations |
| OIG | Office of Inspector General |
| OLA | OSIRIS-REx Laser Altimeter |
| OLI | Operational Land Imager |
| OMB | Office of Management and Budget |
| OMDA | Other Missions and Data Analysis |
| OMI | Ozone Monitoring Instrument |
| OMPS | Ozone Mapping and Profiler Suite |
| OMPS-L | Ozone Mapping and Profiler Suite Limb Sounder |
| ONERA | Office National d’Etudes et Recherches Aérospatiales |
| OP&E | Operation Planning and Execution |
| OPeNDAP | Open Source Project for a Network Data Access Protocol |
| OPM | Office of Personnel Management |
| Orb-# | Orbital Sciences Commercial Resupply Services # |
| ORR | Operational Readiness Review |
| OSC | Orbital Sciences Corporation |
| OSCAR | Optical Science Center for Applied Research |
| OSHA | Occupational Safety and Health Administration |
| OSIRIS-REx | Origins, Spectral Interpretation, Resource Identification, and Security - Regolith Explorer |
| OSMA | Office of Safety and Mission Assurance |
| OSTM | Ocean Surface Topography Mission |
| OSTST | Ocean Surface Topography Science Team |
| OTE | Optical Telescope Element |
| OTES | OSIRIS-REx Thermal Emission Spectrometer |
| OTIS | Optical Telescope element/Integrated |
| OVIRS | OSIRIS-REx Visible and Infrared Spectrometer |
| OVWST | Ocean Vector Winds Science Team |
| OWST | Ocean Winds Science Team |
| P.L. | Public Law |
| PACE | Pre-Aerosol, Clouds, and ocean Ecosystem |
| PAH | polyaromatic hydrocarbons |
| PAMSS | Planetary Atmosphere Minor Species Sensor |
| Pan-STARRS | Panoramic Survey Telescope and Rapid Reporting System |
| PARASOL | Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar |
| PB | President’s Budget |
| PBI | Predominantly Black Institution |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| PBRE | Packed Bed Reactor Experiment |
| PCA | Physicians' comparability allowance |
| PCB | polychlorinated biphenyls |
| PCM | Post Certification Mission |
| PCOS | Physics of the Cosmos |
| PDA | progressive damage analysis |
| PDR | Preliminary Design Review |
| PDS | Planetary Data System |
| PEA | Program Element Appendix |
| PEA-P | Program Element Appendix |
| PEP | Particle Environment Package |
| PI | Principle Investigator |
| PIR | Program Implementation Review |
| PIV | Personal Identity Verification |
| PLSS | Portable Life Support System |
| POWER | Protecting Our Workers and Ensuring Reemployment |
| PP/CC | Planetary Protection/Contamination Control |
| PPS | Precipitation Processing System |
| PSI | Physical Sciences Informatics |
| PSL | Propulsion Systems Laboratory |
| PTRR | Program Transition Readiness Review |
| Pu | plutonium |
| PUFFER | Pop Up Flat Folding Exploration Robots |
| PV | Planetary Ventures, LLC |
| PVT | Psychomotor Vigilance Task |
| QM-1 | qualification motor 1 |
| QuikSCAT | Quick Scatterometer |
| R&A | Research and Analysis |
| R&D | research and development |
| R&T | Research and Technology |
| RAD | Radiation Assessment Detector |
| RAIF | Research Aircraft Integration Facility |
| RAO | Right Anterior Oblique |
| RAP | Robotics Alliance Project |
| RBA | Reflector Boom Assembly |
| RBI | Radiation Budget Instrument |
| RCA | Rapid Cycle Amine |
| RCC | Range Control Center |
| RCO | reduced crew operations |
| REDD | Reducing Emissions from Deforestation and forest Degradation |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| RESOLVE | Regolith and Environment Science and Oxygen and Lunar Volatiles Extraction |
| REXIS | Regolith X-ray Imaging Spectrometer |
| RF | radio frequency |
| RFC | Regenerative Fuel Cell |
| RFI | request for information |
| RFP | request for proposal |
| RFU | Radio Frequency Unit |
| RHESSI | Ramaty High Energy Solar Spectroscopic Imager |
| RID | Research Infrastructure Development |
| RIME | Radar for Icy Moons Exploration |
| RISE | Revolutionize the ISS for Science and Exploration (HEOMD) |
| RISE | Rotation and Interior Structure Experiment (Earth Science) |
| ROD | Record of Decision |
| ROIC | Read-Out Integrated Circuit |
| ROSA | Roll-Out Solar Array |
| ROSES | Research Opportunities in Space and Earth Sciences |
| RPM | revolutions per minute |
| RPO | rendezvous and proximity operations |
| RPS | Radioisotope Power Systems |
| RPT | Rocket Propulsion Test |
| RRM | Robotic Refueling Mission |
| RRS | Research Range Services |
| RS | reflected solar |
| RTCA | Radio Technical Commission for Aeronautics |
| RTG | Radioisotope Thermoelectric Generator |
| RVLT | Revolutionary Vertical Lift Technology |
| SAA | Space Act Agreement |
| SAC-D | Satellite for Scientific Applications-D |
| SAFFIRE | Spacecraft Fire Experiment |
| SAGE | Stratospheric Aerosol and Gas Experiment |
| Sage III | Stratospheric Aerosol and Gas Experiment III |
| SALMON-2 | Second Stand Alone Missions of Opportunity Notice |
| SAM | Sample Analysis at Mars (Planetary Science) |
| SAM I | Stratospheric Aerosol Measurement |
| SAO | Smithsonian Astrophysical Observatory |
| SAR | Synthetic Aperture Radar |
| SARDA | Spot and Runway Departure Advisor |
| SASO | Safe Autonomous Systems Operations |
| SBA | Small Business Administration |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| SBIR | Small Business Innovation Research |
| SCaN | Space Communications and Navigation |
| SCAP | Strategic Capabilities Asset Program |
| SCCS | Spaceport Command and Control System |
| SDO | Solar Dynamics Observatory |
| SDR | System Definition Review |
| SDS | Space Debris Sensor |
| SDSS | Sloan Digital Sky Survey |
| SEAP | STEM Education and Accountability Projects |
| SeaWiFS | Sea-viewing Wide Field-of-View Sensor |
| SEIS | Seismic Experiment for Interior Structure |
| SEO | Science Enhancement Option |
| SEP | solar energetic particles (Heliophysics) |
| SEP | solar electric propulsion (HEOMD/STMD) |
| SERENA | Search for Exospheric Refilling and Emitted Natural Abundances |
| SET | Space Environment Testbeds |
| SETAG | Space Environmental Testing Assets Group |
| SEWP | Solutions for Enterprise-Wide Procurement |
| SEXTANT | Station Explorer for X-ray Timing and Navigation Technology |
| SFCO | Space Flight Crew Operations |
| SFS | Space and Flight Support |
| SGP | Space Geodesy Project |
| SGSS | Space Network Ground Segment Sustainment |
| SHPO | State Historic Preservation Office |
| SIM | Spectral Irradiance Monitor |
| SIP | Strategic Implementation Plan |
| SIPS | Science Investigator-led Processing Systems |
| SIR | System Integration Review |
| SL-8 | SpaceLoft-8 |
| SLD | super-cooled large droplet |
| SLI | Sustainable Land Imaging |
| SLPSRA | Space Life and Physical Sciences Research and Applications |
| SLPSRAD | Space, Life, and Physical Sciences Research and Applications Division |
| SLS | Space Launch System |
| SMA | Safety and Mission Assurance |
| SMAP | Soil Moisture Active Passive |
| SMART-NAS | Shadow Mode Assessments Using Realistic Technologies for the National Airspace System |
| SMD | Science Mission Directorate |
| SMEX | Small Explorers |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| SMOS | Soil Moisture and Ocean Salinity |
| SMS | Safety and Mission Success |
| SNC | Sierra Nevada Corporation |
| SOC | Solar Orbiter Collaboration |
| SOFIA | Stratospheric Observatory for Infrared Astronomy |
| SOHO | Solar and Heliospheric Observatory |
| SoloHI | Solar Orbiter Heliospheric Imager |
| SORCE | Solar Radiation and Climate Experiment |
| SOST | Subcommittee on Ocean Science and Technology |
| SOT | Solar Optical Telescope |
| Space Grant | National Space Grant College and Fellowship Program |
| SpaceX | Space Exploration Technologies Corporation |
| SPB | Solar Pressure Balloon |
| SPDF | Space Physics Data Facility |
| SPHERES | Synchronized Position Hold, Engage, Reorient, and Experimental Satellites |
| SPHERES-Halo | Synchronized Position, Hold, Engage, Reorient, Experimental Satellites – Halo |
| SPIDER | Suborbital Polarimeter for Inflation Dust and the Epoch of Reionization |
| SPOC | Science Processing and Operations Center |
| SPoRT | Short-term Prediction Research and Transition |
| SPP | Solar Probe Plus |
| SpX-# | Space Exploration Technologies Company Commercial Resupply Services # |
| SR&T | Strategic Research and Technology |
| SRB | Standing Review Board |
| SRC | Sample Return Capsule |
| SRFO | Student Research Flight Opportunity |
| sRLV | Suborbital Reusable Launch Vehicle |
| SRP | supersonic retrorocket propulsion |
| SRR | System Requirements Review |
| SRR | Sample Return Robot (Space Tech) |
| SSC | Stennis Space Center |
| SSERVI | Solar System Exploration Research Virtual Institute |
| SSFL | Santa Susana Field Laboratory |
| SSL | Space Systems Loral |
| SSMS | Safety, Security, and Mission Services |
| SST | Small Spacecraft Technology |
| ST | Space Technology |
| STD | standard |
| STEM | Science, Technology, Engineering, and Mathematics |
| STEREO | Solar Terrestrial Relations Observatory |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| STIP | Strategic Technology Investment Plan |
| STMD | Space Technology Mission Directorate |
| STP | Solar Terrestrial Probes |
| STP H-5 LIS | Space Test Program Houston-5 Lightning Imaging System |
| STPH-5 LIS | Space Test Program Houston-5 Lightning Imaging System |
| STR&D | Space Technology Research and Development |
| STRG | Space Technology Research Grants |
| STScI | Space Telescope Science Institute |
| STTR | Small Business Technology Transfer |
| SUBSA | Solidification Using a Baffle in Sealed Ampoules |
| Suomi NPP | Suomi National Polar-Orbiting Partnership |
| SWEAP | Solar Wind Electrons Alphas and Protons |
| SWIR | shortwave infrared |
| SWOT | Surface Water Ocean Topography |
| SwRI | Southwest Research Institute |
| SXS | Soft X-Ray Spectrometer |
| TACP | Transformative Aeronautics Concepts Program |
| TAGSAM | Touch and Go Sample Acquisition Mechanism |
| TASEAS | Technologies for Assuring Safe Energy and Attitude State |
| TBD | to be determined |
| TBO | Trajectory Based Operations |
| TBW | Truss Braced Wing |
| TCL | technical capability level |
| TCTE | Total Solar Irradiance Calibration Transfer Experiment |
| TCU | Tribal Colleges and Universities |
| TDM | Technology Demonstration Missions |
| TDRS | Tracking and Data Relay Satellite |
| TDRSS | TDRS System |
| TDT | Transonic Dynamics Tunnel |
| TechPort | Technology Portfolio System |
| TEMPEST-D | Temporal Experiment for Storms and Tropical Systems-Demonstrator |
| TEMPO | Tropospheric Emissions: Monitoring of Pollution |
| TES | Tropospheric Emission Spectrometer |
| TESS | Transiting Exoplanet Survey Satellite |
| TFM | Traffic Flow Management |
| TGO | Trace Gas Orbiter |
| THEMIS | Time History of Events and Macroscale Interactions during Substorms |
| THOR | Terrestrial HIAD Orbital Reentry |
| TIM | Total Irradiance Monitor |
| TIMED | Thermosphere Ionosphere Mesosphere Energetics and Dynamics |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| TIR-FFD | Thermal-Infrared Free-Flyer |
| TIRS | Thermal Infrared Sensor |
| TMC | Technical, Management, and Cost |
| TMPA | TRMM Multi-satellite Precipitation Analysis |
| TOC | Total Organic Carbon |
| TPS | Thermal Protection System |
| TR&T | Targeted Research & Testing |
| TrACE | Tri-Agency Climate Education |
| TRACT | Transport Rotorcraft Airframe Crash Testbed |
| TRL | Technology Readiness Level |
| TRMM | Tropical Rainfall Measuring Mission |
| TRN | Terrain Relative Navigation |
| TSAS | Terminal Sequencing and Spacing |
| TSI | total solar irradiance |
| TSIS | Total and Spectral Solar Irradiance Sensor |
| TSIS-1 | Total Solar Irradiance Sensor-1 |
| TSIS-2 | Total Solar Irradiance Sensor-2 |
| TSS | Terminal Sequencing and Spacing |
| TTT | Transformational Tools and Technologies |
| TWINS | Two Wide-angle Imaging Neutral-atom Spectrometers |
| U.S.C. | United States Code |
| UAS | Unmanned Aircraft Systems |
| UAVSAR | Uninhabited Aerial Vehicle Synthetic Aperture Radar |
| UEST | ultra-efficient subsonic transport |
| UHB | ultra-high bypass |
| UHF | ultra high frequency |
| UKSA | United Kingdom Space Agency |
| UL | Underwriter's Laboratory |
| ULA | United Launch Alliance |
| ULS | United Launch Services |
| UN | United Nations |
| UNEX | University-Class Explorers |
| upGREAT | Upgraded German REceiver for Astronomy at Terahertz Frequencies |
| UPS | uninterrupted power supply |
| UPSS | Universal Propellant Servicing System |
| UPTWT | Unitary Plan Wind Tunnel |
| USAF | U.S. Air Force |
| USAID | United States Agency for International Development |
| USDA | U.S. Department of Agriculture |
| USGCRP | U.S. Global Change Research Program |

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| USGS | U.S. Geological Survey |
| USIP | Undergraduate Student Information Project |
| USRA | Universities Space Research Association |
| UTM | UAS Traffic Management |
| UTRC | United Technologies Research Center |
| UVS | Ultraviolet Spectrograph |
| VAB | Vehicle Assembly Building |
| VAC | Vertical Assembly Center |
| VAFB | Vandenberg Air Force Base |
| VCLS | Venture Class Launch Service |
| VEGGIE | Vegetable Production System |
| VERITAS | Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy |
| VIIP | visual impairment and intracranial pressure |
| VIIRS | Visible Infrared Imaging Radiometer Suite |
| VIL | Vehicle Integration and Launch |
| VLT | Very Large Telescope |
| VSPT | Variable-Speed Power Turbine |
| WANs | Wide Area Networks |
| WASP | Web Application Security Program |
| WBS | work breakdown structure |
| WCF | Working Capital Fund |
| Webb | James Webb Space Telescope |
| WFA | Work from Anywhere |
| WFF | Wallops Flight Facility |
| WFIRST | Wide Field Infrared Survey Telescope |
| WISE | Wide-field Infrared Survey Explorer |
| WISPR | Wide-Field Imager for Solar Probe Plus |
| WIYN | Wisconsin–Madison, Indiana University, Yale University, and National Optical Astronomy Observatory |
| WSTF | White Sands Test Facility |
| XMM-Newton | X-ray Multi-Mirror Mission |
| ZBOT | Zero Boil-Off Tank |