United States Government Accountability Office

Report to Congressional Committees

December 2016

# JAMES WEBB SPACE TELESCOPE

## Project Meeting Cost and Schedule Commitments but Continues to Use Reserves to Address Challenges

GAO-17-71

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GAO Highlights

Highlights of GAO-17-71, a report to congressional committees

## Why GAO Did This Study

JWST is one of NASA's most complex and expensive projects, at an anticipated cost of $8.8 billion. Now in the midst of significant integration and testing that will last the 2 remaining years until the planned October 2018 launch date, the JWST project will need to continue to address many challenges and identify problems, some likely to be revealed during its rigorous testing. The continued success of JWST hinges on NASA's ability to anticipate, identify, and respond to these challenges in a timely and cost-effective manner to meet its commitments.

Conference Report No. 112-284, accompanying the Consolidated and Further Continuing Appropriations Act, 2012, included a provision for GAO to assess the project annually and report on its progress. This is the fifth such report. This report assesses the extent to which JWST is (1) managing technological and developmental challenges to meet its schedule commitments, and (2) meeting its committed cost levels and managing its workforce plans. To conduct this work, GAO reviewed monthly JWST reports, reviewed relevant policies, conducted independent analysis of NASA and contractor data, and interviewed NASA and contractor officials.

## What GAO Recommends

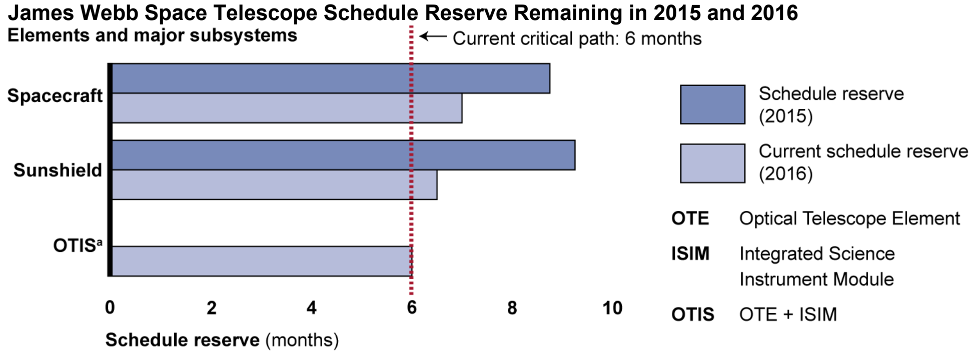
GAO is not making recommendations in this report. GAO has made recommendations in previous reports, to which NASA has generally agreed and taken steps to implement. There are three recommendations that NASA has not fully implemented that could still benefit the JWST project.

View GAO-17-71. For more information, contact Cristina Chaplain at (202) 512-4841 or chaplainc@gao.gov.

## What GAO Found

The National Aeronautics and Space Administration's (NASA) James Webb Space Telescope (JWST) project is still operating within its committed schedule while in its riskiest phase of development, integration and test. Most hardware deliveries and two of five major integration and test efforts have been completed. Two other integration and test efforts are underway, with the final effort to begin in fall 2017. JWST used about 3 months of schedule reserve since GAO's last report in December 2015. For example, the project used one month of schedule reserve to address delays in integrating the Optical Telescope Element and the Integrated Science Instrument module, due to the complexity of this effort. The project's remaining 6 months of reserve is more than required by Goddard Space Flight Center requirements, as determined by project officials. The figure below shows JWST's elements and major subsystems, the schedule reserve remaining for each, and the critical path—the schedule with the least amount of reserve.

**James Webb Space Telescope Schedule Reserve Remaining in 2015 and 2016**




Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-17-71

[a] In 2015, the ISIM and OTE elements were in separate integration efforts. In 2016, they were integrated into the OTIS element and are depicted as a single integration and test effort.

JWST is one of NASA's most technologically complex science projects and has numerous risks and single points of failure, which need to be tested and understood before launch. The project also faces a number of risks related to the observatory software. Looking ahead, the project will likely need to consume more reserves for its complex integration and test efforts.

JWST is meeting its cost commitments despite technical and workforce challenges. Although the project used $42.8 million more than planned for fiscal year 2016, it is maintaining spending within the levels dictated by the 2011 replan. NASA continues to emphasize that maintaining schedule is the priority, which resulted in the use of the fiscal year 2016 cost reserves to meet technical challenges. Also, as GAO previously found in December 2015, the observatory contractor has continued to maintain a larger workforce for longer than planned in order to address technical issues. For example, in 2016, the observatory contractor averaged 165 full-time equivalents more than projected to address technical issues while minimizing the impact on schedule. The contractor submitted a proposal to NASA this summer to cover cost overruns, which was the first such proposal since the replan in 2011.

# Contents

## Abbreviations

| | |
|---|---|
| I&T | integration and test |
| ISIM | Integrated Science Instrument Module |
| JPL | Jet Propulsion Laboratory |
| JWST | James Webb Space Telescope |
| MIRI | Mid-Infrared Instrument |
| NASA | National Aeronautics and Space Administration |
| OTE | Optical Telescope Element |
| OTIS | Optical Telescope Element and Integrated Science Instrument Module |
| STScI | Space Telescope Science Institute |

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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December 7, 2016

Congressional Committees

The James Webb Space Telescope (JWST) is one of the National Aeronautics and Space Administration's (NASA) most complex projects and top priorities. It is intended to revolutionize our understanding of star and planet formation and advance the search for the origins of our universe. The innovative technologies within the telescope as well as the sheer size of some of its components—such as the tennis-court-sized sunshield—illustrate some of the immense challenges in building it. The project has now entered into a period of significant integration and test activities for its elements and major subsystems. During this period, unforeseen challenges could arise and affect the cost and schedule for the project. Until its launch, planned for October 2018, NASA and its contractors' continued ability to identify and respond to challenges in a timely and cost-effective manner will likely influence whether JWST can meet its cost and schedule commitments to Congress.

The on-time and on-budget delivery of JWST is also a high congressional priority, as Conference Report No. 112-284 included a provision for GAO to assess the JWST program annually and to report to the Committees on Appropriations on key issues relating to program and risk management, achievement of cost and schedule goals, program technical status, and oversight mechanisms.[1] This report is our fifth in response to that provision. For this report, we assessed the extent to which the JWST project is (1) managing technological issues and development challenges to maintain its committed schedule, and (2) meeting its committed cost levels and managing its workforce plans.

Our approach included an examination of the schedule, technical, and cost performance of the project since our last report in December 2015—which also focused on the project's cost and schedule commitments and the extent to which independent oversight provided insight to management about project risks.[2] To assess the extent to which JWST is

[1]H.R. Rep. No. 112-284, at 254 (2011).

[2]GAO, *James Webb Space Telescope: Project on Track but May Benefit from Improved Contractor Data to Better Understand Costs*, GAO-16-112 (Washington, D.C.: Dec. 17, 2015).

managing technological issues and development challenges to maintain its committed schedule, we reviewed project and contractor schedule documentation, monthly project status reports, selected individual risks from monthly risk registers, and other documentation. We also held interviews with program, project, and contractor officials on the progress made and challenges faced building and integrating the various elements and major subsystems of the observatory. To assess the extent to which JWST is meeting its committed cost levels and managing its workforce plans, we analyzed program, project, and contractor data and documentation. We compared projected workforce levels to actual workforce levels to determine differences and their effect on cost.

We conducted this performance audit from February 2016 to December 2016 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

## Background

JWST is envisioned to be a large deployable, infrared-optimized space telescope and the scientific successor to the aging Hubble Space Telescope. JWST is being designed for a 5-year mission to find the first stars and trace the evolution of galaxies from their beginning to their current formation, and is intended to operate in an orbit approximately 1.5 million kilometers—or 1 million miles—from the Earth. With a 6.5-meter primary mirror, JWST is expected to operate at about 100 times the sensitivity of the Hubble Space Telescope. JWST's science instruments are to observe very faint infrared sources and as such are required to operate at extremely cold temperatures. To help keep these instruments cold, a multi-layered tennis-court-sized sunshield is being developed to protect the mirrors and instruments from the sun's heat. The JWST project is divided into three major segments: the observatory segment, the ground segment, and the launch segment. When complete, the observatory segment of JWST is to include several elements (Optical Telescope Element (OTE), Integrated Science Instrument Module (ISIM), and spacecraft) and major subsystems (sunshield and cryocooler).[3] The

[3]The cryocooler is an interdependent two-stage cooler subsystem designed to bring the infrared light detector within JWST's Mid-Infrared Instrument to the required temperature of 6.7 Kelvin.

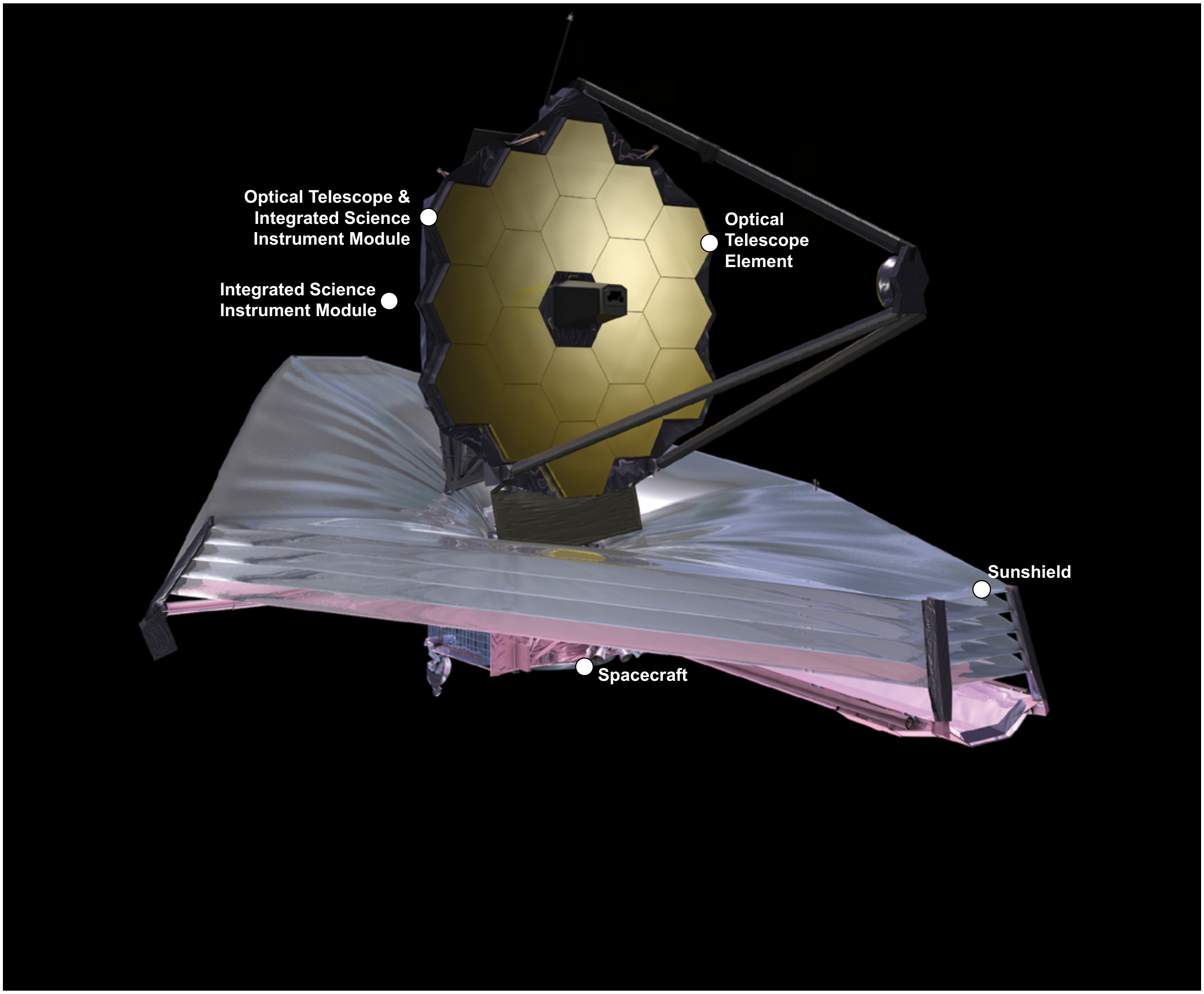
hardware configuration created when the Optical Telescope Element and the Integrated Science Instrument Module are integrated, referred to as OTIS, is not considered an element by NASA, but we categorize it as such for ease of discussion. Additionally, JWST is dependent on software to deploy and control various components of the telescope as well as collect and transmit data back to Earth. The elements, major subsystems, and software are being developed through a mixture of NASA, contractor, and international partner efforts. See figure 1 below for an interactive graphic that depicts the elements and major subsystems of JWST.[4]

[4]The ground segment is not pictured in figure 1, the interactive graphic.

**Figure 1: James Webb Space Telescope**

Interactive Graphic

Rollover the white dots to see description. See appendix II for the non-interactive, printer-friendly version.




Sources: GAO (analysis); National Aeronautics and Space Administration (NASA) (data and images). | GAO-17-71

For the majority of the work remaining, the JWST project will rely on three contractors: Northrop Grumman Corporation, Harris Corporation (formerly Exelis), and the Association of Universities for Research in Astronomy's Space Telescope Science Institute (STScI). Northrop Grumman plays the largest role, developing the sunshield, the OTE, the spacecraft, the cryocooler for the Mid-Infrared Instrument, and integrating and testing the observatory. Northrop Grumman performs most of this work under a contract with NASA, but its work on the Mid-Infrared Instrument (MIRI) cooler is performed under a separate subcontract with the Jet Propulsion Laboratory (JPL). Harris is manufacturing the test equipment, equipping the test chamber, and assisting in the testing of the optics of JWST. Finally, STScI will solicit and evaluate research proposals from the scientific community and will receive and store the scientific data collected, both of which are services that they currently provide for the Hubble Space Telescope. Additionally, STScI is developing the ground system that manages and controls the telescope's observations and will operate the observatory on behalf of NASA.

JWST depends on 22 deployment events—more than a typical science mission—to prepare the observatory for normal operations on orbit. For example, the sunshield and primary mirror are designed to fold and stow for launch to fit within the launch vehicle payload fairing and deploy once in space. Due to its large size, it is nearly impossible to perform deployment tests of the fully assembled observatory, so the verification of deployment elements on JWST is accomplished by a combination of lower level component tests in flight-simulated environments; ambient deployment tests for assembly, element, and observatory levels; and detailed analysis and simulations at various levels of assembly.

## Cost and Schedule Reserves for NASA Projects

Complex development efforts like JWST face myriad risks and unforeseen technical challenges, which oftentimes can become apparent during integration and testing. To accommodate these risks and unknowns, projects reserve extra time in their schedules—which is referred to as schedule reserve—and extra money in their budgets—which is referred to as cost reserve. Schedule reserve is allocated to specific activities, elements, and major subsystems in the event there are delays or to address unforeseen risks. Each JWST element and major subsystem has been allocated schedule reserve. When an element or major subsystem exhausts schedule reserve, it may begin to affect schedule reserve on other elements or major subsystems whose progress is dependent on prior work being finished for its activities to proceed. The element or major subsystem with the least amount of schedule reserve determines the critical path for the project. Any delay to an activity that is on the critical path will reduce schedule reserve for the whole project, and could ultimately impact the overall project schedule.

Cost reserves are additional funds within the project manager's budget that can be used to address unanticipated issues for any element or major subsystem and are used to mitigate issues during the development of a project. For example, cost reserves can be used to buy additional materials to replace a component or, if a project needs to preserve schedule reserve, reserves can be used to accelerate work by adding shifts to expedite manufacturing and save time. NASA's Goddard Space Flight Center (Goddard)—the NASA center with responsibility for managing JWST—has issued procedural requirements that establish the levels of both cost and schedule reserves that projects must hold at various phases of development.[5] In addition to cost reserves held by the project manager, management reserves are funds held by the contractors that allow them to address cost increases throughout development. We have found that management reserves should contain 10 percent or more on the cost to complete a project and are used to address different issues.[6]

## History of Cost Growth, Low Project Reserves, and Schedule Delays

JWST has experienced significant cost increases and schedule delays. Prior to being approved for development, cost estimates of the project ranged from $1 billion to $3.5 billion with expected launch dates ranging from 2007 to 2011. Before 2011, early technical and management challenges, contractor performance issues, low level cost reserves, and poorly phased funding levels caused JWST to delay work after confirmation, which contributed to significant cost and schedule overruns, including launch delays. The Chair of the Senate Subcommittee on Commerce, Justice, Science, and Related Agencies requested from NASA an independent review of JWST in June 2010. In response, NASA commissioned the Independent Comprehensive Review Panel, which issued its report in October 2010, and concluded that JWST was executing well from a technical standpoint, but that the baseline funding did not reflect the most probable cost with adequate reserves in each

[5]Goddard Space Flight Center, Goddard Procedural Requirements 7120.7 (May 4, 2008).

[6]GAO, *NASA: Earned Value Management Implementation across Major Spaceflight Projects Is Uneven*, GAO-13-22 (Washington, D.C.: Nov. 19, 2012); and *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, GAO-09-3SP (Washington, D.C.: Mar. 2, 2009).

year of project execution, resulting in an unexecutable project.[7] Following this review, the JWST program underwent a replan in September 2011, and Congress in November 2011 placed an $8 billion cap on the formulation and development costs for the project. On the basis of the replan, NASA rebaselined JWST with a life-cycle cost estimate of $8.835 billion that included additional money for operations and a planned launch in October 2018. The revised life-cycle cost estimate included a total of 13 months of funded schedule reserve.[8]

## Previous GAO Reviews of JWST Project

We have previously found that since the project's replan in 2011, the JWST project has met its cost and schedule commitments.[9] Most recently, in December 2015, we found that the JWST project was meeting its schedule commitment established at the replan but would soon face some of its most challenging integration and testing.[10] All of the project's elements and major subsystems were within weeks of becoming the project's critical path—the schedule with the least amount of reserve—for the overall project. The project had yet to begin 3 of 5 integration and test events, where problems are most often identified and schedules begin to slip, while working to address over 100 identified technical risks and to ensure that potential causes of mission failure were fully tested and understood. We further found that JWST continued to meet its cost commitments, but that larger than planned workforce levels, particularly with the observatory contractor, posed a threat to meeting cost commitments. Additionally, unreliable contractor data could pose a risk to project management. We recommended that the JWST project require contractors to identify, explain, and document anomalies in contractor-

[7] James Webb Space Telescope (JWST) Independent Comprehensive Review Panel (ICRP): Final Report (Oct. 29, 2010).

[8] The 2011 baseline plan had 13 months of schedule reserve. However, by accelerating some work, the project was able to increase the schedule reserve to 14 months in June 2012.

[9] GAO, *James Webb Space Telescope: Project Facing Increased Schedule Risk with Significant Work Remaining,* GAO-15-100 (Washington, D.C.: Dec. 15, 2014); *James Webb Space Telescope: Project Meeting Commitments but Current Technical, Cost, and Schedule Challenges Could Affect Continued Progress,* GAO-14-72 (Washington, D.C.: Jan. 8, 2014); and *James Webb Space Telescope: Actions Needed to Improve Cost Estimate and Oversight of Test and Integration,* GAO-13-4 (Washington, D.C.: Dec. 3, 2012).

[10] GAO-16-112.

delivered monthly earned value management reports.[11] NASA concurred with this recommendation and, in February 2016, directed the contractors to implement the actions stated in the recommendation.

We have made recommendations in previous reports with regard to improving cost and schedule estimating, updating risk assessments, and strengthening management oversight. NASA has generally agreed and taken steps to implement a number of our recommendations; however, there are three recommendations that NASA has not fully implemented that could still benefit the JWST project.

## JWST Is Maintaining Schedule Commitment with Significant Integration and Test Efforts Underway

The project has completed most of its major hardware deliveries including the telescope, instrument module, and the majority of the spacecraft. The project has also made significant advances on the sunshield and cryocooler, two major subsystems that have historically posed challenges. Two of five planned integration efforts are complete and two more are currently underway. The project has used 8 months of its schedule reserve to address technical challenges, but is maintaining its schedule commitment. The project's schedule reserve, currently 6 months, remains above the Goddard Space Flight Center requirement, as determined by project officials, and is on track with the project's more conservative internal plan. Integrating the Optical Telescope Element (OTE) and Integrated Science Instrument Module (ISIM) into the combined OTE+ISIM (OTIS) element has taken longer than initially planned and is currently the critical path for the project. As a result, the reserve allocated to the remaining OTIS integration and test work, including a cryovacuum test that takes 93 days to complete, has been reduced from 3 to 2 months. However, risk reduction tests on pathfinder hardware have mitigated issues that would likely have consumed additional schedule reserves during OTIS testing. As we also found in 2015, other JWST elements and major subsystems are within weeks of becoming the project's critical path, which could further reduce schedule reserves.[12] As we have previously reported, integration and testing is the phase where problems are most likely to be found and schedules tend to

[11]Earned value management is an important project management tool that, when properly used, can provide accurate assessments of project progress, produce early warning signs of impending schedule delays and cost overruns, and provide unbiased estimates of anticipated costs at completion.

[12]GAO-16-112.

slip. Thus, going forward, technical issues encountered are more likely to require critical path schedule reserves to address.

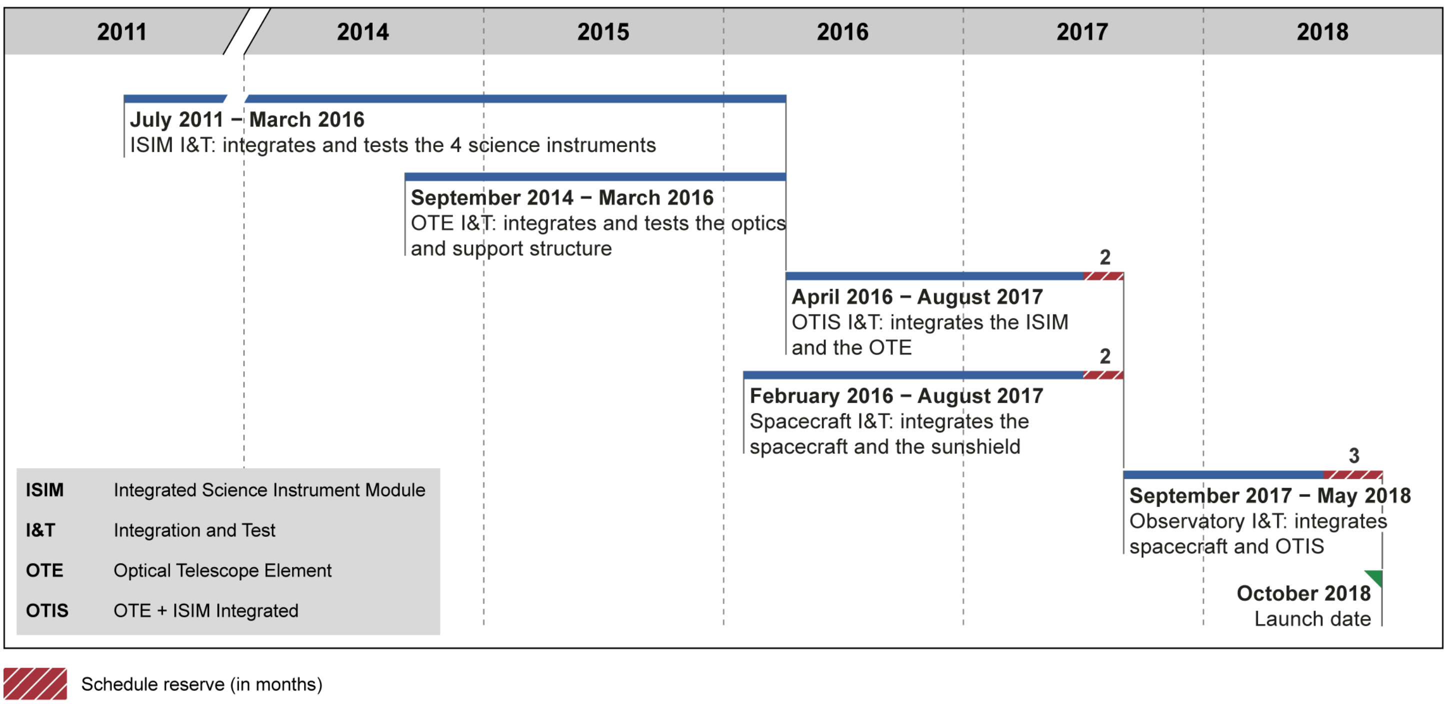
## Project Has Made Significant Progress on Hardware Deliveries and Integration Work

The project and its contractors have delivered the majority of the observatory's hardware, including the telescope, instrument module, and the majority of the spacecraft components. These deliveries also include significant advances on two subsystems that have historically been sources of numerous technical challenges and delays. For example, Northrop Grumman received the sunshield's final membrane layer from its subcontractor in September 2016, following a delay of over 3 months. This delay in delivery of the final sunshield membrane layer capstones a series of challenges Northrop Grumman and its subcontractor have experienced with the membranes. According to Northrop Grumman officials, their subcontractor struggled to deliver the membranes on time due to a variety of technical factors including additional time needed to seam the last layers with a new lot of material, additional testing requirements, and facility limitations. Technical challenges with the membranes were further complicated by Northrop Grumman's difficulty in addressing the resulting schedule issues with their subcontractor.

After an 18-month delay and numerous technical challenges, the cryocooler compressor assembly was delivered by the subcontractor to the Jet Propulsion Laboratory in July 2015, where it met its acceptance and end-to-end testing requirements. The Jet Propulsion Laboratory then delivered the compressor and electronics assemblies to Northrop Grumman for spacecraft integration and test in May 2016, about 9 weeks ahead of the need date that was based on a revised schedule. Over the last several years, the project has accommodated a series of cryocooler schedule slips by reordering and compressing the Jet Propulsion Laboratory's test schedule and resequencing the spacecraft integration schedule. Some additional work on the cryocooler will be carried forward into spacecraft integration and test, including completion of vibration verification of refrigerant lines and related hardware that was augmented after cryocooler vibration testing had been completed and confirming bonding resistance of cryocooler hardware when it is integrated with the spacecraft. Jet Propulsion Laboratory officials characterized residual risks as minor and the additional work required at the higher level of integration as typical. JWST project officials further stated that the cryocooler's performance in testing was excellent and met all of its requirements with healthy margin, and that they are comfortable with the work that will be carried forward into spacecraft integration and test.

With most major hardware deliveries complete, the project is primarily focused on integrating and testing the individual elements and major subsystems that compose the observatory. Specifically, the project and Northrop Grumman completed two of five planned integration efforts—the instrument module and the telescope elements—respectively, in March 2016. Two additional integration efforts—integrating the OTE and ISIM into the OTIS element and integrating the spacecraft—are underway, as illustrated in figure 2.

**Figure 2: Integration and Test (I&T) Schedule for the James Webb Space Telescope**



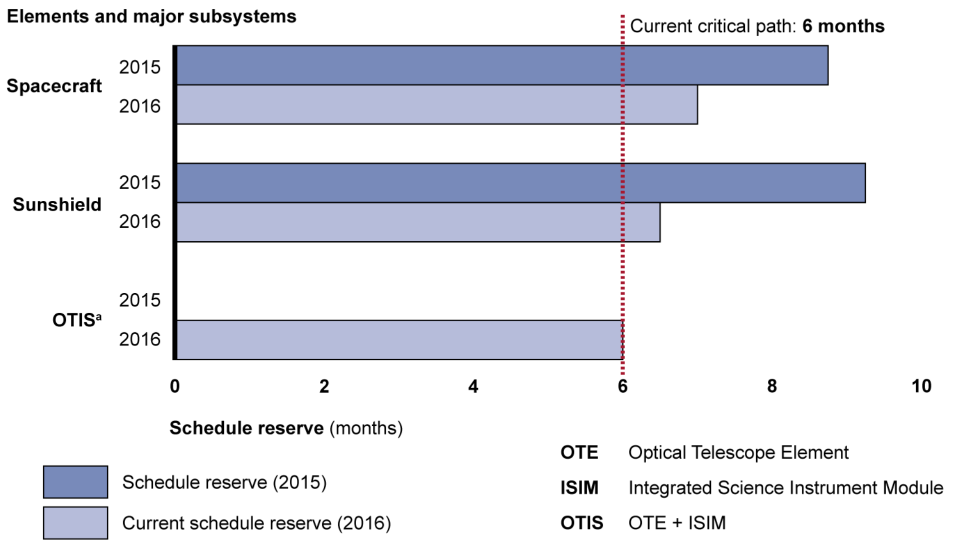

Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-17-71

Note: There are multiple lower level I&T efforts that flow into the ISIM, OTE, and Spacecraft I&T flow that are not depicted on figure 2. For example, the sunshield is a major subsystem that has its own I&T effort that runs parallel to spacecraft I&T. Also, the project has allocated one month of its overall schedule reserves for the launch site that is not depicted on figure 2.

## Project Has Consumed Schedule Reserve to Mitigate Technical Issues with Critical Integration Work Still Ahead

The project has consumed 8 of 14 total months of its overall schedule reserve to address technical challenges across elements and major subsystems. Almost 3 months of this reserve have been consumed within the past year. The remaining 6 months of reserve is more than required by Goddard Space Flight Center, as determined by project officials, and on track with the project's more conservative internal plan—which was set above the Goddard standard at the replan in 2011. The OTIS integration and test work is currently the project's critical path. However, as we also found in 2015, all of JWST's elements and major subsystems are within weeks of moving onto the critical path, increasing the likelihood of further use of schedule reserve.[13] While the project plans to use all its available schedule reserve to mitigate issues as it approaches launch, the proximity of each element to the critical path means that the project must prioritize the mitigations when problems occur. See Figure 3 below for a comparison of the schedule reserve held by each element and major subsystem in 2016, compared to last year.

**Figure 3: Schedule Reserve Held by Each Element and Major Subsystem for the James Webb Space Telescope in 2015 and 2016**




Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-17-71

[a]In 2015, the ISIM and OTE elements were in separate integration efforts. In 2016, they were integrated into the OTIS element and are depicted as a single integration and test effort.

[13]GAO-16-112.

Each of JWST's elements and major subsystems have experienced technical issues that, while reducing their individual schedule reserves as shown in Figure 3 above, also consumed overall project critical path schedule reserve in the past year.

**OTIS:** In August 2016, the project designated one month of critical path schedule reserve to the OTIS element integration effort. According to the project, a portion of the additional time was needed due to the complexity inherent in integrating the telescope and instruments. For example, project officials explained that work progressed slower than planned because of the manual nature of the work and physical reach and access limitations, which created a more serial work flow, particularly with installing over 900 thermal blankets. Additionally, the project addressed concerns regarding contamination control in the clean room.

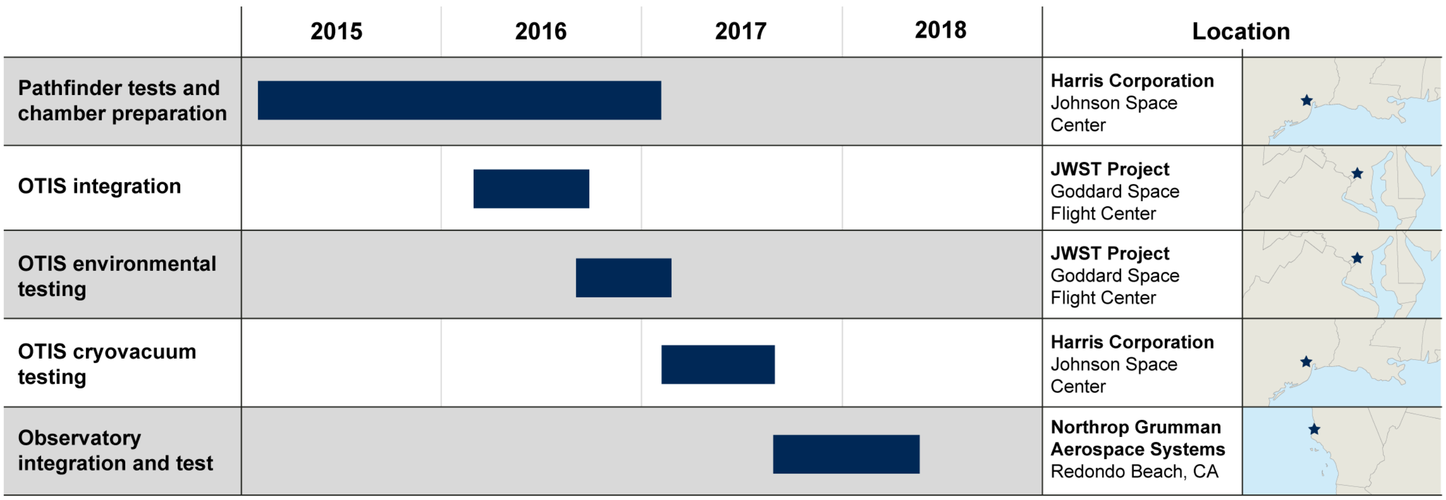
The project took steps to optimize the OTIS integration and test flow to minimize critical path schedule impact. For example, the project conducted some tasks in parallel and added more work shifts to minimize the length of time to complete a task. In addition to addressing integration challenges, a portion of the one month was designated for the chamber operations and preparation work to be conducted at Johnson Space Center in advance of the OTIS cryovacuum test—the final event in the OTIS integration and test effort—based on lessons learned from the integration and test work that has occurred thus far. As a result, the reserve allocated for the OTIS integration and test effort has been reduced from 3 to 2 months. If an issue occurred that required stopping and repeating the cryovacuum test, which is planned to take 93 days, the remaining 2 months of OTIS reserve before the observatory integration and test effort begins, could easily be exhausted and consume reserve allocated for later integration and test work. Figure 4 shows the OTIS element.

**Figure 4: James Webb Space Telescope's Optical Telescope Element and Integrated Science Instrument Module**

Source: National Aeronautics and Space Administration (NASA). | GAO-17-71

In an effort to allow OTIS testing to proceed more smoothly and prevent the use of additional schedule reserve, the project and its contractor for OTIS testing, Harris Corporation, have undertaken a series of three risk reduction tests on pathfinder hardware at Johnson Space Center. Optical ground support equipment tests 1 and 2 were completed in June and October 2015, respectively, and the third and final risk reduction test, Thermal Pathfinder, was completed in October 2016, after a 3-month delay to update the processes for cooling down the chamber. The pathfinder work was conducted in parallel to instrument, telescope, and OTIS integration and test activities and was scheduled to conclude in time to begin the OTIS cryovacuum test in early 2017. See figure 5 below.

**Figure 5: Optical Telescope Element + Integrated Science Instrument Module (OTIS) Integration and Test Schedule Flow**




JWST = James Webb Space Telescope

Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-17-71

The pathfinder tests have allowed the project and Harris to practice processes and procedures that will be used for the eventual OTIS cryovacuum testing and validate the performance of ground support equipment. This is intended to create a more efficient test flow and proactively address issues before the test on flight hardware commences. For example, the second pathfinder test showed that vibration levels inside the test chamber were too high, and adjustments to the ground support equipment were implemented to address this issue. Additionally, after the second pathfinder test, the project discovered that the adhesive on the back of the tape used throughout the observatory can flake and release particles at cryogenic temperatures, which raised concerns about contamination of sensitive hardware, particularly in the instrument module. Because these issues were discovered during the pathfinder tests, the project was able to address them before OTIS testing where flight hardware could have been affected and prevent the use of additional schedule reserve.

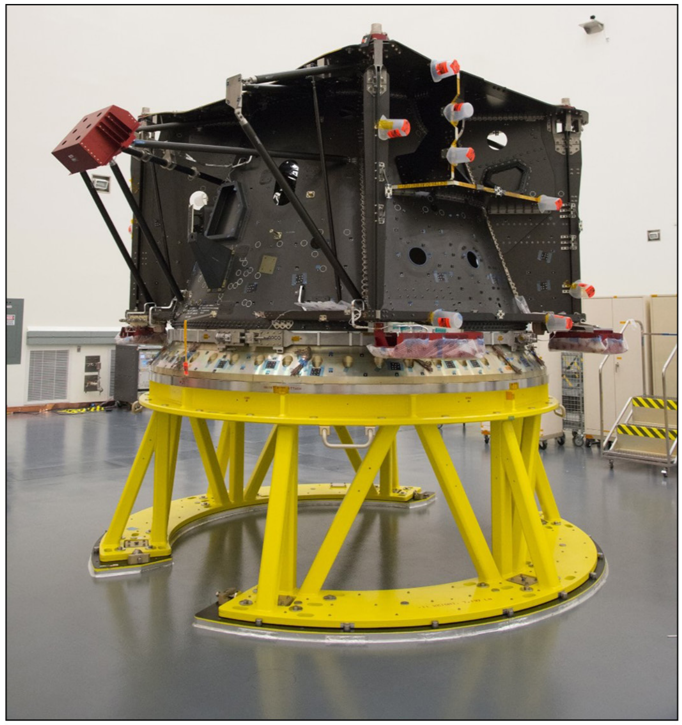
**Sunshield:** The sunshield experienced several issues, which in total reduced schedule reserves by 7 weeks and required adjustments to the integration and test flow at Northrop Grumman to minimize further schedule impacts. For example, in October 2015, the project reported that a piece of flight hardware for the sunshield's mid-boom assembly was irreparably damaged during vacuum sealing in preparation for shipping. The damaged piece had to be remanufactured, which consumed 3 weeks of schedule reserve. In January 2016, subcontractor manufacturing delays with the individual sunshield membrane layers consumed 2 additional weeks of schedule reserves. Most recently, in June 2016, Northrop Grumman redesigned the membrane tensioning system, which allows the sunshield to unfold and maintain its shape when deployed. According to contractor officials, during previous mass reduction efforts, the pulley walls in the system were thinned out; however, when tested under higher loads, the weaker walls allowed a cable to become pinched during a test. Because the observatory now has sufficient mass margin, the system was redesigned to thicken the walls. The redesign of the system consumed an additional 2 weeks of schedule reserves, and the project is tracking further schedule threats related to conducting an anti-corrosion chemical treatment of the system's parts and investigating a deployment test anomaly. To accommodate the 2-week slip and minimize use of additional schedule reserves, Northrop Grumman adjusted its planned sunshield and spacecraft integration and test flow. For example, delivery of the structures that support the sunshield will now be delayed from September to December 2016. Sunshield integration needs to be completed by September 2017 to avoid delaying integration and testing of the completed observatory. Figure 6 shows the full scale sunshield templates used for testing the deployment of the sunshield.

**Figure 6: James Webb Space Telescope's Sunshield Template Layers**

Source: National Aeronautics and Space Administration (NASA). | GAO-17-71

**Spacecraft:** The spacecraft consumed 4 weeks of schedule reserves due to a variety of technical challenges, particularly with the electronics and propulsion components. For example, 2 weeks of reserves were consumed in January 2016 due to a deficient test cable which caused a vibration test anomaly, following the late delivery of spacecraft electronics components from the supplier. According to program officials, a series of assembly issues on the propulsion system consumed another 2 weeks of reserves. For example, installation and welding of the spacecraft propellant lines was more complicated and took more time than expected. Additionally, Northrop Grumman discovered that, during spacecraft check out testing, components in the propulsion system that are used to measure fuel levels had been damaged due to operator error. The damaged parts will require replacement and the project and Northrop Grumman continue to track this issue as a schedule threat. Due to the technical issues experienced, the reserves allocated for spacecraft integration and test have been reduced from 3 to 2 months. However, significant integration and test work remains. Specifically, Northrop Grumman will complete integration of the cryocooler electronics and compressor assemblies and spacecraft electronics panels into the spacecraft bus structure, conduct the first comprehensive system test in 2016, and begin integration testing in early 2017. Figure 7 shows the spacecraft.

Figure 7: James Webb Space Telescope's Spacecraft



Source: National Aeronautics and Space Administration (NASA). | GAO-17-71

In an effort to provide additional schedule margin, the JWST project has been working with the launch vehicle provider on the possibility of expanding the potential launch window. According to program officials, at its former expected mass and due to its planned trajectory and its relationship to the moon, JWST could not launch for a period before and after the solstices. This means if it misses the planned October 2018 launch date, the project would have to wait until February 2019 for another opportunity. However, prior mass reduction efforts have made the observatory lighter and resulted in more flexibility in launch dates near the winter solstice.

## Complexity of JWST Underscores Integration and Test Risks

JWST is one of the most technologically complex science projects NASA has undertaken. In addition to the previously noted challenges that have reduced schedule reserves, much significant and technologically challenging work remains to be completed in the 2 years remaining before launch, which could further erode schedule reserves if problems occur. As integration and testing moves forward, the project will need to be able to reduce a significant amount of risk and address technical challenges in a timely manner to stay on schedule.

The project maintains a list of risks—currently with 73 items—that need to be tested and mitigated to an acceptable level in the remaining 2 years before launch. According to the project, approximately 25 of these risks are not likely to be closed until the conclusion of the observatory integration and test effort—just prior to project launch. In some cases, the project will determine that no further mitigations are feasible and whether to accept any residual risk. Many of these risks relate to the project's numerous deployments or single point failures.[14] According to project officials, in comparison with other NASA unmanned spaceflight missions, JWST has a greater number of and more complex deployments. The extent of these deployments—which are necessary because the telescope and sunshield must be stowed for launch to fit within the launch vehicle payload fairing—means the telescope could fail to operate as planned in an extensive number of ways. For example, the four release mechanisms that hold the spacecraft and OTE together for launch are key deployments, as well as potential single point failures, for the project. Once in space, these mechanisms are to activate and release to allow the OTE to separate from the spacecraft. If the mechanisms fail to deploy, or release prematurely, mission failure could occur. The project has redesigned the mechanisms due to excessive shock when performing the release function, and efforts to qualify the new design and mitigate as much of the risk of failure or premature release as possible are ongoing.

According to project officials, there are over 100 different single point failure modes across hundreds of individual items in the observatory, nearly half of which involve the deployment of the sunshield. To ensure that all deployment mechanisms are ready for flight, Northrop Grumman—with participation from the project—is conducting a series of deployment reviews using standards developed by the contractor and employed on a variety of systems with large, complex, or high risk mission deployments. These reviews are tailored to the more rigorous requirements of JWST and provide a phased series of assessments throughout the mission's development. The project is also seeking a waiver from NASA's Office of Safety and Mission Assurance for its numerous single point failures throughout the observatory, including

[14]A single point failure is an independent element of a system, the failure of which would result in loss of objectives or hardware.

those related to the sunshield. The approval of critical single point failures requires justification from the project including sound engineering judgement, supporting risk analysis, and implementation of measures to mitigate the risk to acceptable levels. According to project officials, this approach is consistent with other high-priority NASA missions, which require the most stringent design and development approach that NASA takes to ensure the highest level of reliability and longevity on orbit. Additionally, program officials noted that NASA leadership has been well informed of JWST's potential single point failures, and that the items covered in the waiver are well understood and expected.

JWST also faces a number of risks related to software integration. According to NASA's Independent Verification and Validation office—which independently examines mission critical software development for most NASA programs and projects, the project is unique among spaceflight projects in the amount and complexity of the software required to operate it and the number of developers contributing the software. For example, while most science programs or projects have two to four software developers, JWST has eight. This creates inherent cost and schedule risk for the project. The project is tracking a number of software-related risks throughout the observatory. However, NASA's Independent Verification and Validation officials stated that they believe that JWST is on track to continue meeting its software milestones, but the testing that lies ahead—when the different components are integrated—will be a challenge. Going forward, NASA's Independent Verification and Validation office will be focusing its efforts on the software related to the ongoing OTIS integration and test work.

Our prior work has shown that integration and testing is the phase in which problems are most likely to be found and schedules tend to slip. For a complex project such as JWST, this risk is magnified. Now that the project is well into its complex integration and test efforts, events are more sequential in nature and there are few opportunities to mitigate issues in parallel. According to contractor officials, opportunities for schedule work-arounds and recovery options, which have preserved some schedule reserves in the past, are diminishing. Thus, going forward, technical issues encountered during integration and test are more likely to require critical path schedule reserves to address, as has recently been observed in the OTIS integration and test effort.

## JWST Continues to Meet Cost Commitments Amid Technical and Workforce Challenges

**Program and Project Reserves**

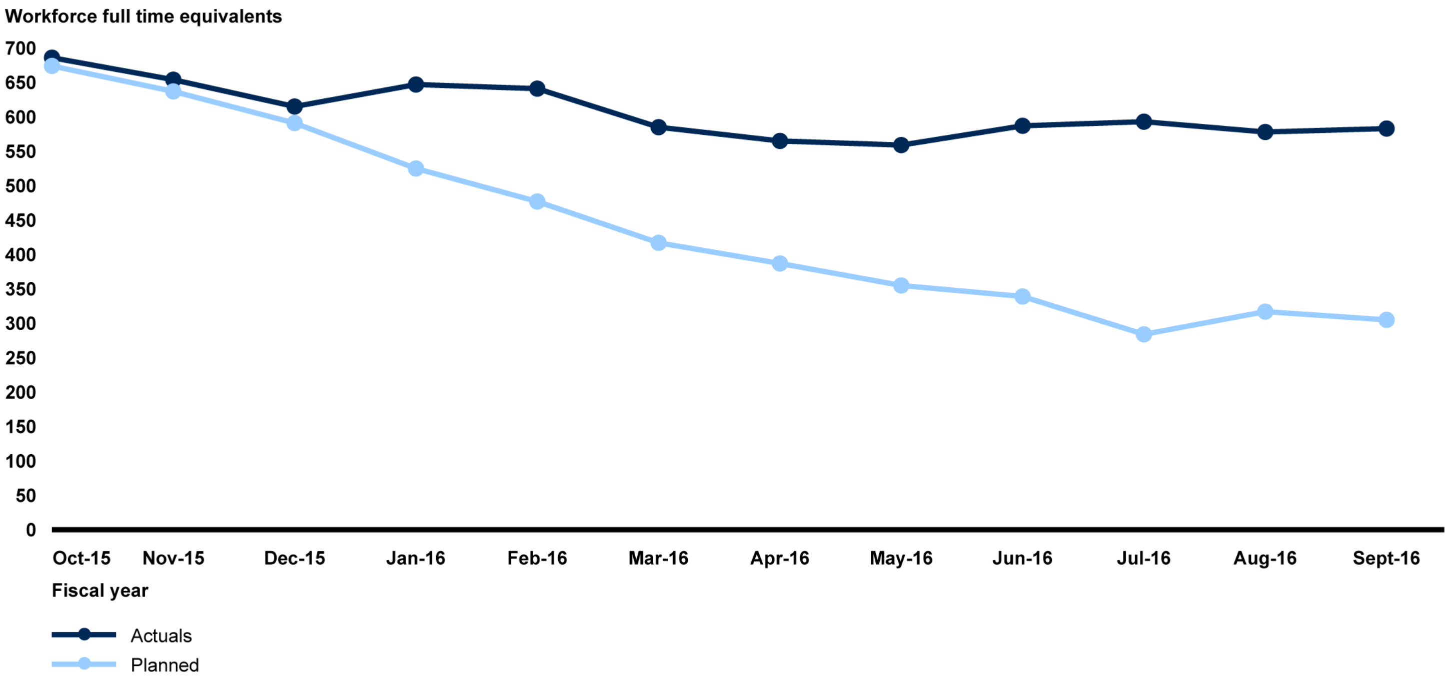
Project reserves are those costs that are expected to be incurred but have not yet been allocated to a specific project cost element. A project's reserves may be held at the project level, program level, and mission directorate level. The project's reserves are divided and portions are controlled by the project manager, the program and mission directorate.

Source: GAO summary of NASA data

Though the project spent $42.8 million more than planned for fiscal year 2016, project officials managed JWST within its allocated budget for the fifth consecutive year since the 2011 replan. The project estimates that it will carry over into fiscal year 2017 about half of the amount it projected. NASA officials attribute the reduced amount of carry over to their emphasis on maintaining schedule, which has required additional dollars to meet technical challenges. As in past years, the project used a portion of its cost reserves to address technical challenges, such as completing OTIS integration. The project also received additional program-level cost reserves in fiscal year 2016. For example, program-held reserves were used to offset cryocooler costs in fiscal year 2016 for the work remaining. Our analysis indicates that these additional costs will not result in exceeding the project's overall cost commitment. However, NASA has already committed the majority of its fiscal year 2017 program-held reserves to address increased costs on the Northrop Grumman contract. As a result, NASA will have diminished project and program reserves to address technical and other challenges that may occur.

Though 89 percent of the work on the Northrop Grumman contract has been completed, the primary threat to JWST continues to be the ability of Northrop Grumman, the observatory contractor, to control its costs and decrease its workforce. For the past 32 months, Northrop Grumman's actual workforce has exceeded its projections and is not expected to fall to under 300 full-time equivalents until the spring of 2017. Based on its projections at the beginning of the fiscal year, Northrop Grumman exceeded its total fiscal year 2016 workforce monthly projections by about 37 percent. Figure 8 below illustrates the difference between the workforce levels that Northrop Grumman projected at the beginning of fiscal year 2016 and its actual workforce levels for that period.

Figure 8: Northrop Grumman Workforce Levels in Fiscal Year 2016, Projections at Beginning of Fiscal Year versus Actuals




Source: GAO analysis of contractor data. | GAO-17-71

Northrop Grumman's workforce has declined slightly in fiscal year 2016 when compared to fiscal year 2015, but, on average, Northrop Grumman was above its projections by 165 full-time equivalents each month in fiscal year 2016. In the beginning of the fiscal year, Northrop Grumman's workforce was close to projected levels. However, in the latter half of the year, the contractor increased its workforce instead of decreasing as projected. For example, in July 2016, Northrop Grumman's workforce was 593 instead of 284 as projected. Almost half of the July increase was due to a need for more workers to work on observatory integration and test activities. According to project officials, Northrop Grumman continues to maintain overall higher workforce levels than planned because the project has asked them to prioritize schedule when addressing technical issues that arise to minimize impacts to the project's schedule. The project, however, has also communicated the need to reduce the workforce size, including holding frequent discussions with the contractor on workforce planning. As Northrop Grumman hardware schedule milestones are completed, NASA expects the contractor to reduce its workforce accordingly.

While Northrop Grumman did consume fiscal year 2016 reserves to address technical issues and challenges, it was able to operate within budget for fiscal year 2016. However, in July 2016, Northrop Grumman submitted its first cost overrun proposal to NASA since the replan in 2011. The costs associated with Northrop Grumman's higher workforce levels is the primary reason for their overrun proposal. The project had independently forecasted that Northrop Grumman costs would be higher than anticipated as the contractor dealt with technical issues and cost increases for critical hardware deliveries such as the sunshield and spacecraft. Currently, the project is evaluating Northrop Grumman's proposal, including the impact on program cost reserves, and does not expect to conclude negotiations before early 2017.

While Northrop Grumman is developing and manufacturing large portions of the observatory, as well as integrating and testing the observatory, NASA relies on other entities for other support, components, and observatory operations. For example, Harris Corporation is manufacturing the test equipment used to test the OTIS flight hardware. Since most of the work performed by these entities is complete or has a significantly lower contract value than the observatory contractor, it is unlikely that it will result in JWST exceeding its cost commitments as a result. For example;

**Harris Corporation:** Projected costs will likely overrun the contract when it completes the work performed under this contract in December 2016, but our analysis shows that it will not cause JWST to exceed its cost commitment. In 2017, Harris will perform additional work on JWST, but that work will be performed through a Goddard Space Flight Center support contract rather than a contract specifically for JWST.

**Jet Propulsion Laboratory:** In fiscal year 2016, the laboratory overran its cost for work related to JWST and the project used budget reserves to cover additional costs. Overall, in developing and testing the cryocooler system, the Jet Propulsion Laboratory costs grew about 258 percent and consumed a disproportionate amount of JWST reserves. Because most of the work remaining for JPL is complete—testing of the spare cryocooler remains—it is unlikely that cryocooler costs will have any significant impact on JWST cost reserves in the future.

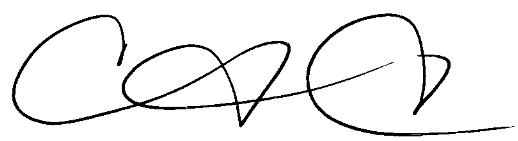
**Space Telescope Science Institute:** The STScI has generally performed work within planned costs. To gain further insight on its costs, NASA has an ongoing effort to require the institute to provide earned value management data on its JWST contract. STScI has submitted its proposal on how it will meet this new requirement and a contract modification is expected to be executed in January 2017.

## Agency Comments and our Evaluation

We requested comments from NASA, but agency officials determined that no formal comments were necessary. NASA provided technical comments, which were incorporated as appropriate.

We are sending copies of the report to NASA's Administrator and interested congressional committees. In addition, the report will be available at no charge on GAO's website at http://www.gao.gov.

Should you or your staff have any questions on matters discussed in this report, please contact me at (202) 512-4841 or chaplainc@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made major contributions to this report are listed in appendix III.



Cristina T. Chaplain
Director
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# Appendix I: Objectives, Scope, and Methodology

Our objectives were to assess the extent to which the James Webb Space Telescope (JWST) project is (1) managing technological issues and development challenges to maintain its committed schedule and (2) meeting its committed cost levels and managing its workforce plans.

To assess the extent to which the JWST project is managing technological issues and development challenges to maintain its committed schedule, we reviewed project and contractor schedule documentation, and held interviews with program, project, and contractor officials on the progress made and challenges faced building and integrating the different components of the observatory. We examined and analyzed monthly project status reports to management to monitor schedule reserve levels and usage and potential risks and technical challenges that may impact the project's schedule, and to gain insights on the project's progress since our last report in December 2015. Further, we attended flight program reviews at the National Aeronautics and Space Administration (NASA) headquarters on a quarterly basis, where the current status of the program was briefed to NASA headquarters officials outside of the project. We examined selected individual risks for elements and major subsystems from monthly risk registers prepared by the project to understand the likelihood of occurrence and impacts to the schedule based on steps the project is taking to mitigate the risks. We examined test schedules and plans to understand the extent to which risks will be mitigated. Furthermore, we interviewed project officials at Goddard, contractor officials from the Northrop Grumman Corporation, the Harris Corporation, the Jet Propulsion Laboratory, and the Association of Universities for Research in Astronomy's Space Telescope Science Institute concerning technological challenges that have had an impact on schedule, and the project's and contractor's plans to address these challenges.

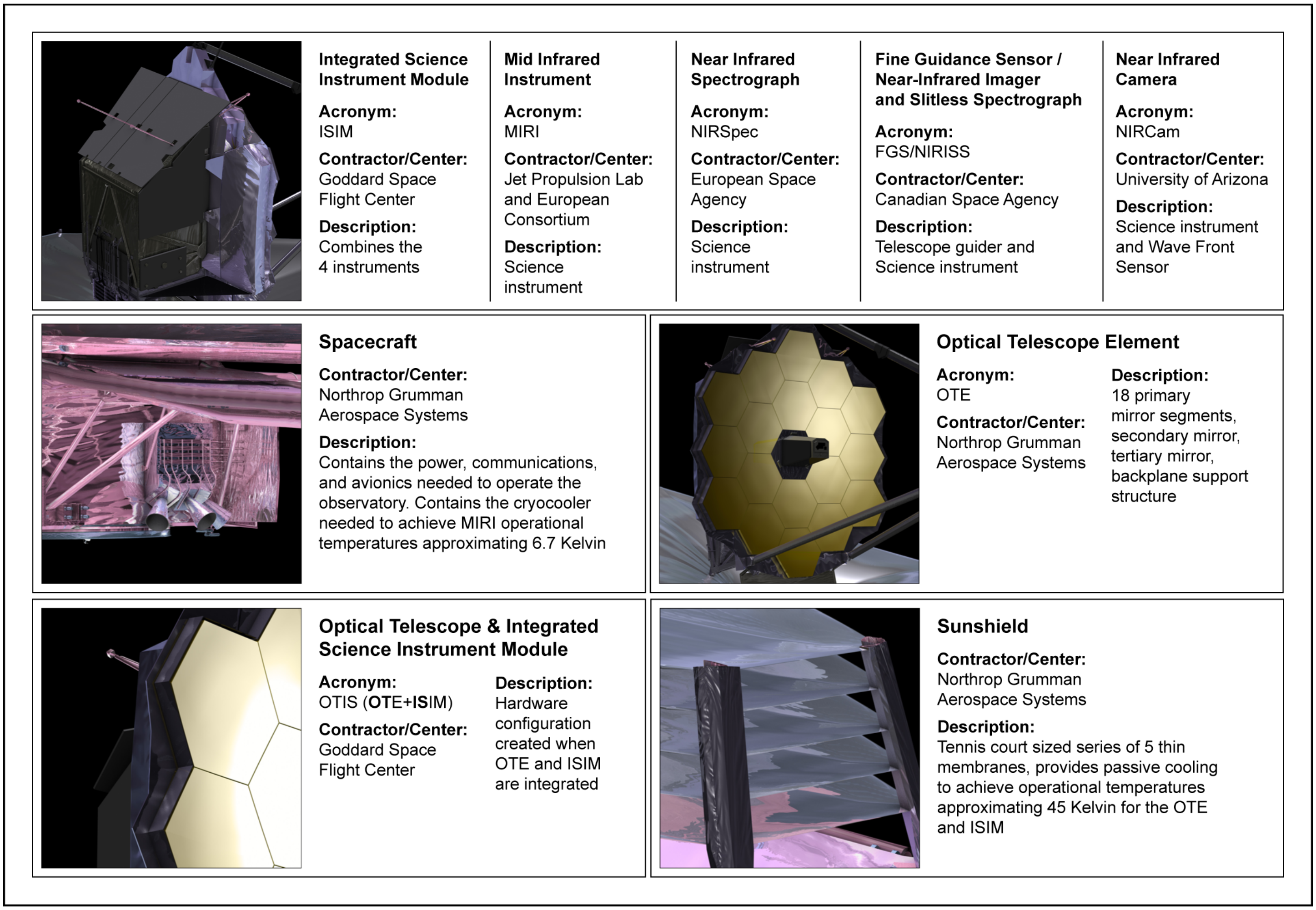
To assess the extent to which the JWST project is meeting its committed cost levels and managing its workforce plans, we reviewed and analyzed program, project, and contractor data and documentation and held interviews with officials from these organizations. We reviewed JWST project status reports on cost issues to determine the risks that could impact cost. We analyzed contractor workforce plans against workforce actuals to determine whether contractors' are meeting their workforce plans. We monitored and analyzed the status of program, and project cost reserves in current and future fiscal years to determine the project's financial posture. We examined and analyzed earned value management data from two of the project's contractors to identify trends in performance, whether tasks were completed as planned and likely estimates at completion.

Our work was performed primarily at NASA headquarters in Washington, D.C.; Goddard Space Flight Center in Greenbelt, Maryland; Northrop Grumman Corporation in Redondo Beach, California; and the Space Telescope Science Institute in Baltimore, Maryland. We also conducted interviews at the Independent Verification and Validation facility in Fairmont, West Virginia; the Harris Corporation, Chester, Maryland; and the Jet Propulsion Laboratory in Pasadena, California.

We conducted this performance audit from February 2016 to December 2016 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

# Appendix II: Elements and Major Subsystems of the James Webb Space Telescope (JWST) Observatory

**Figure 9: Elements and Major Subsystems of the James Webb Space Telescope (JWST) Observatory**




Sources: GAO (analysis); National Aeronautics and Space Administration (NASA) (data and images). | GAO-17-71

# Appendix III: GAO Contact and Staff Acknowledgments

## GAO Contact

Cristina Chaplain, (202) 512-4841 or chaplainc@gao.gov.

## Staff Acknowledgments

In addition to the contact named above, Richard Cederholm, Assistant Director; Karen Richey, Assistant Director; Jay Tallon, Assistant Director; Molly Traci, Assistant Director; Marie P. Ahearn; Brian Bothwell; Laura Greifner; Katherine Lenane; Jose Ramos; Carrie Rogers; and Roxanna Sun made key contributions to this report.

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