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Report to Congressional Committees

February 2018

JAMES WEBB SPACE TELESCOPE

Integration and Test Challenges Have Delayed Launch and Threaten to Push Costs Over Cap

GAO-18-273

GAO Highlights

Highlights of GAO-18-273, a report to congressional committees

February 2018

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Why GAO Did This Study

JWST, a large, deployable telescope intended to be the successor to the Hubble Space Telescope, is one of NASA's most complex and expensive projects, at an anticipated cost of $8.8 billion. Congress set an $8 billion JWST development cost cap in 2011, and the remaining $837 million is for its operations costs. JWST is intended to revolutionize our understanding of star and planet formation and advance the search for the origins of our universe. With significant integration and testing planned for the remaining period until launch, the JWST project will still need to address many challenges during the remainder of integration and testing.

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 sixth such report. This report assesses the extent to which JWST is (1) meeting its schedule commitments, and (2) able to meet its cost commitments. 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

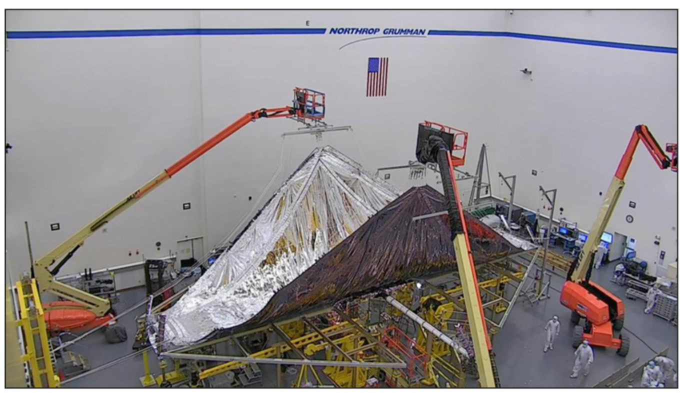
GAO has made recommendations on the project in previous reports. NASA agreed with and took action on many of GAO's prior recommendations, but not on others—some of which may have provided insight to the current schedule delays. For example, in December 2012, GAO recommended that the JWST project perform an updated integrated cost/schedule risk analysis.

View GAO-18-273. For more information, contact Cristina T. Chaplain at (202) 512-4841 or chaplainc@gao.gov

What GAO Found

In 2017, the National Aeronautics and Space Administration's (NASA) James Webb Space Telescope (JWST) project delayed its launch readiness date by at least 5 months, and further delays are likely. The delay—from October 2018 to a launch window between March and June 2019—was primarily caused by components of JWST's spacecraft taking longer to integrate than planned. JWST made considerable progress toward the completion of integration and test activities in the past year. However, the project used all remaining schedule reserve—or extra time set aside in the schedule in the event of delays or unforeseen risks—to address technical issues, including an anomaly on the telescope found during vibration testing. Extending the launch window provided the project up to 4 months of schedule reserve. However, shortly after requesting the new launch window in September 2017, the project determined that several months of schedule reserve would be needed to address lessons learned from the initial folding and deployment of the observatory's sunshield (see image). Given remaining integration and test work ahead—the phase in development where problems are most likely to be found and schedules tend to slip—coupled with only 1.5 months of schedule reserves remaining to the end of the launch window, additional launch delays are likely. The project's Standing Review Board will conduct an independent review of JWST's schedule status in early 2018 to determine if the June 2019 launch window can be met.

James Webb Space Telescope's Sunshield Folding Operation at the Contractor Facility



Source: Northrop Grumman. | GAO-18-273

JWST will also have limited cost reserves to address future challenges, such as further launch delays, and is at risk of breaching its $8 billion cost cap for formulation and development set by Congress in 2011. For several years, the prime contractor has overestimated workforce reductions, and technical challenges have prevented these planned reductions, necessitating the use of cost reserves. Program officials said that existing program resources will accommodate the new launch window—provided remaining integration and testing proceeds as planned without any long delays. However, JWST is still resolving technical challenges and work continues to take longer than planned to complete. As a result, the project is at risk of exceeding its $8 billion formulation and development cost cap.

Contents

Abbreviations

ESA	European Space Agency
Goddard	Goddard Space Flight Center
I&T	integration and test
ISIM	Integrated Science Instrument Module
JCL	Joint Cost and Schedule Confidence Level
JWST	James Webb Space Telescope
NASA	National Aeronautics and Space Administration
OTE	Optical Telescope Element
OTIS	Optical Telescope Element and Integrated Science Instrument Module
STScI	Space Telescope Science Institute

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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, which 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 development challenges. The project is now in the midst of 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, as evidenced by a recent announcement that JWST delayed its launch readiness date by 5 to 8 months because of technical challenges. Until its launch, 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 commitments to Congress and avoid further schedule delays.

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 sixth in response to that provision. For this report, we assessed the extent to which (1) the JWST project is managing technical challenges and integration risks in order to meet its schedule commitments, and (2) technical challenges and higher-than-planned contractor workforce levels are affecting the JWST project's ability to meet its cost commitments.

To address these objectives, we examined the schedule, technical, and cost performance of the project since our last report in December 2016—which also focused on the project's cost and schedule commitments.[2] To

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

[2]GAO, *James Webb Space Telescope: Project Meeting Cost and Schedule Commitments but Continues to Use Reserves to Address Challenges*, GAO-17-71 (Washington, D.C.: Dec. 7, 2016).

assess the extent to which the JWST project is managing technical challenges and integration risks in order to meet its schedule commitments, we reviewed project and contractor schedule documentation, and held interviews with program, project, and contractor officials on the progress made and any 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 2016. 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 the project's schedule risk assessment to determine the impact of technical challenges and schedule execution rates on the project's planned launch readiness date. Furthermore, we interviewed project officials at Goddard Space Flight Center, contractor officials from the Northrop Grumman Corporation, 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. We also obtained information from independent NASA reviewers on the status of project software and challenges.

To assess the extent to which technical challenges and higher-than-planned contractor workforce levels are affecting the JWST project's ability to meet its cost commitments, 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 the project's observatory contractor 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 obtained information from officials at the Independent Verification and Validation facility in Fairmont, West Virginia.

We conducted this performance audit from March 2017 to February 2018 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 space telescope, optimized for infrared observations, and the scientific successor to the aging Hubble Space Telescope. JWST is being designed for a 5-year mission to find the first stars, study planets in other solar systems to search for the building blocks of life elsewhere in the universe, and trace the evolution of galaxies from their beginning to their current formation. JWST 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 designed to observe very faint infrared sources and therefore 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 hardware configuration created when the Optical Telescope Element and the Integrated Science Instrument Module were integrated, referred to as

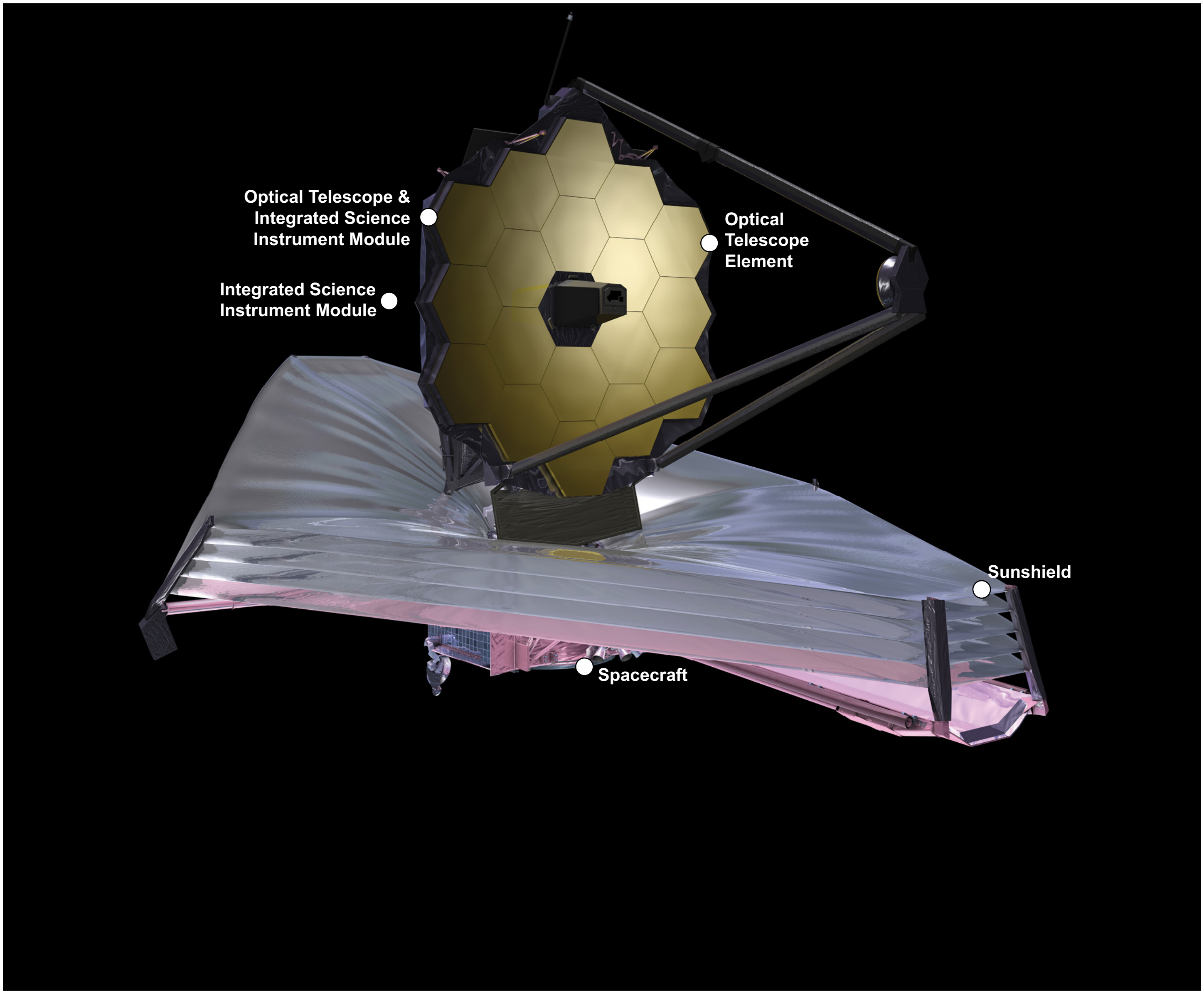
[3]The cryocooler is an interdependent two-stage cooler subsystem designed to bring the infrared light detector within JWST's Mid-Infrared Instrument to the required temperature of 6.7 Kelvin.

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, and to 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 for an interactive graphic that depicts the elements and major subsystems of JWST.

Figure 1: James Webb Space Telescope

Interactive Graphic

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



Sources: GAO (analysis); National Aeronautics and Space Administration (NASA) (data and images). | GAO-18-273

For the majority of work remaining, the JWST project is relying on two contractors: Northrop Grumman Corporation 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 Optical Telescope Element, the spacecraft, and the Mid-Infrared Instrument's cryocooler, in addition to integrating and testing the observatory. STScI's role includes soliciting and evaluating research proposals from the scientific community, and receiving and storing the scientific data collected, both of which are services that it currently provides 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 will be launched on an Ariane 5 rocket, provided by the European Space Agency.

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 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 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.

Schedule and Cost Reserves for NASA Projects

We have previously reported that complex development efforts like JWST face numerous risks and unforeseen technical challenges, which oftentimes can become apparent during integration and testing. To accommodate unanticipated challenges and manage risk, 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 of 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. 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.[4] 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 of the cost to complete a project and are generally used to address various issues tied to the contract's scope.[5]

History of Cost Growth 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 cost and schedule baselines were established, 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.

[4]NASA, Goddard Procedural Requirements 7120.7, Schedule and Budget Margins for Flight Projects (May 4, 2008); Goddard projects are required to hold two months of funded schedule reserve per year from the start of integration and test to shipment to launch site, and are required to hold cost reserves equal to at least 25 percent at the project confirmation review, and 10 percent or higher at the time of delivery to the launch site.

[5]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).

NASA commissioned the Independent Comprehensive Review Panel, which issued its report in October 2010, and concluded that the baseline funding did not allot adequate reserves, resulting in an unexecutable project.[6] Following this review, the JWST program underwent a replan in September 2011, and in November of that same year, Congress 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 which included additional money for operations and a planned launch in October 2018.[7] 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] In our most recent report in December 2016, we found that the project was still operating within its committed schedule while in its riskiest phase of development—integration and test—but had used about 3 months of schedule reserve since our previous December 2015 report.[10] In addition, we found that the project was facing numerous risks and single points of

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

[7]A replan is a process initiated if development cost growth is 15 percent or more. A replan does not require a new project baseline to be established. A rebaseline is a process initiated if development cost growth is more than 30 percent. Both processes require the NASA Administrator to transmit a report to the Committee on Science, Space, and Technology of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate. In addition, if a project or program milestone is likely to be delayed by 6 months or more, a report to the committees is required.

[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 Meeting Cost and Schedule Commitments but Continues to Use Reserves to Address Challenges,* GAO-17-71 *(Washington, D.C.: Dec. 7, 2016); 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); *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-17-71.

failure before launch. Finally, we found that while the project was meeting its cost commitments despite technical and workforce challenges, the observatory contractor had continued to maintain a larger workforce for longer than planned in order to address technical issues. In these prior reports, we have made recommendations 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. For example, in December 2015, we recommended that the JWST project require contractors to identify, explain, and document anomalies in contractor-delivered monthly earned value management reports. NASA concurred with this recommendation and, in February 2016, directed the contractors to implement the actions stated in the recommendation. However, NASA did not implement some recommendations, which if implemented, may have provided insight into the challenges it now faces. For example, in December 2012, we recommended the JWST project update its joint cost and schedule confidence level (JCL), a point-in-time estimate that, among other things, includes all cost and schedule elements and incorporates and quantifies known risks.[11] NASA policy requires projects to establish commitment baselines at a 70 percent confidence level. Although NASA concurred with this recommendation, it did not take steps to implement it. An updated JCL may have portended the current schedule delays, which could have been proactively addressed by the project.

Considerable Progress Made Across JWST Project, but Integration and Test Challenges Have Delayed Launch at Least 5 Months with Further Delays Likely

While much progress on hardware integration and testing and several risk reduction efforts have occurred over the past several months, the JWST project also used all of its schedule reserves established at the replan in 2011 to address various technical issues, including a test anomaly on the telescope and sunshield hardware challenges. In September 2017, the JWST project requested a launch window at least 5 to 8 months later than the planned October 2018 launch readiness date, based on the results of a schedule risk assessment that showed that various components of the spacecraft element integration were taking longer to complete than expected. The new launch window included up to 4 months of additional schedule reserves. However, shortly after requesting the revised launch window from the European Space Agency (ESA), which will contribute the launch vehicle, the project learned from Northrop Grumman that up to another 3 months of schedule reserve use was expected, due to lessons

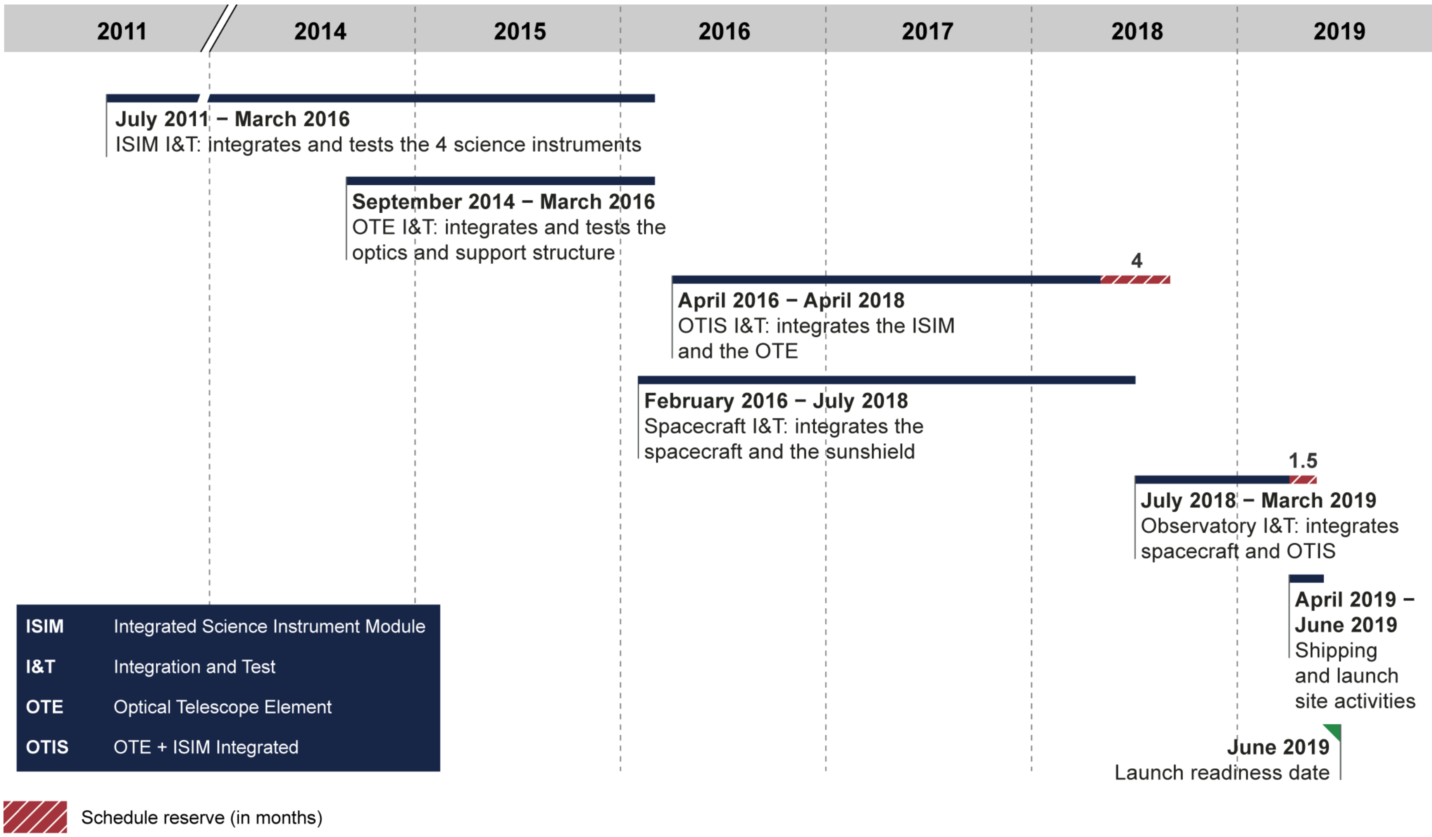
[11] GAO-13-4.

learned from conducting deployment exercises of the spacecraft element and sunshield. After incorporating some schedule efficiencies, the project now has 1.5 months of schedule reserve remaining. Given the remaining integration and test work ahead—the phase in development where problems are most likely to be found and schedules tend to slip—and risks remaining to be reduced to acceptable levels, coupled with a low level of schedule reserves, we believe that additional delays to the project's launch readiness date are likely.

JWST Project Completed Significant Integration and Test Work

Since our last report, the JWST project has made considerable progress toward completing its third and fourth of five total integration and test phases for the combined optical telescope element and integrated science instrument module (OTIS) and the spacecraft elements, respectively. Previously, the project and Northrop Grumman completed the Integrated Science Instrument Module and the Optical Telescope Element integration phases in March 2016, as shown in Figure 2 below.

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-18-273

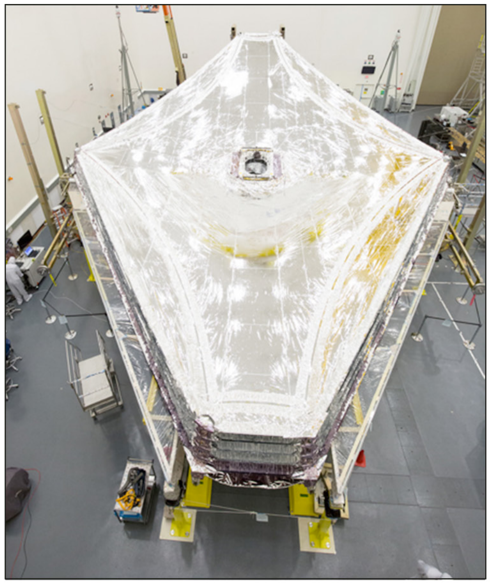
- **OTIS progress:** Hardware integration and two of three key environmental tests—acoustics and vibration—were completed in 2016 and early 2017, respectively. The third key test, cryovacuum—which was conducted in a large cryovacuum chamber to ensure the telescope can operate at the near-absolute zero cryogenic temperatures of space—began in July 2017 at Johnson Space Center and successfully concluded in October 2017. The project identified a technical issue with the stability of the optical mirror that affects image quality, and by conducting some additional testing, determined that it was caused by a test equipment setup issue and not related to the flight hardware itself. Project officials stated that they plan to delay shipping the completed OTIS element to the Northrop Grumman facility in California for final integration with the spacecraft element from late December 2017 to February 2018. According to project officials, the delay allows the project to shift some of the work to prepare OTIS for integration with the spacecraft—such as cleaning the mirrors—to Johnson Space Center where it will not have to share space in the crowded clean room at Northrop Grumman as sunshield fold and stow activities are ongoing. OTIS is expected to arrive at Northrop Grumman months ahead of its need date for integration into the observatory.

Figure 3: Optical Telescope Element and Integrated Science Instrument Module (OTIS) Emerging from Thermal Vacuum Testing Chamber

Source: National Aeronautics and Space Administration. | GAO-18-273

- **Spacecraft element progress:** All spacecraft element hardware has been delivered and mechanical integration of spacecraft hardware—including the five layers of the sunshield—is largely complete. Northrop Grumman has also completed a folding operation and the first full deployment of the integrated spacecraft element. Northrop Grumman plans to refold the sunshield and complete one more deployment cycle, after environmental testing, in this phase of integration and testing.

Figure 4: Flight Sunshield Deployed and Tensioned at Northrop Grumman Facility



Source: Northrop Grumman. | GAO-18-273

The project and its contractors conducted risk reduction testing on OTIS and the spacecraft elements to reduce risk for challenging environmental tests on flight hardware. These tests allowed the project and its contractors to practice processes and procedures for testing on flight hardware to create a more efficient test flow and proactively address issues before flight hardware tests commenced. For example, the second risk reduction test on the OTIS pathfinder hardware 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, Northrop Grumman officials noted that risk reduction tests on the spacecraft element have helped demonstrate facility capability and logistics for the upcoming tests of flight hardware.

The project has also progressed in preparing the software and ground systems that will operate the observatory and manage and control the telescope's observations. According to NASA's Independent Verification and Validation group, the overall status of JWST software development and integration efforts is very positive with minimal development remaining, and the group has significant confidence that the mission software will support the mission objectives. Additionally, the Space Telescope Science Institute has made considerable progress in preparing

JWST's ground systems, such as preparing the Mission Operations Center and conducting the Mission Operations Review in April 2017.

The project has made notable progress in reducing and closing numerous tracked risks. In December 2016, we reported that the project maintained a risk list with 73 items. Currently, the list of tracked risks has 47 items to be closed or mitigated to acceptable levels. The completion of the OTIS cryovacuum test enabled the project to recently close several risks. For example, the project previously tracked a risk that the instrument module and telescope element might have to be de-integrated if OTIS testing revealed workmanship issues. With the successful completion of the testing, this risk was closed in fall 2017. The project also obtained a waiver from the Office of Safety and Mission Assurance to NASA's risk policy for its over 300 single point failures throughout the observatory, the majority of which are related to the sunshield. Project officials reported that the elimination of all single point failures on the JWST Mission is not practical or even feasible, due mainly to the large number of deployments, and that all mitigations practical to address and minimize them have been implemented.

JWST Delayed Launch Due to Integration Challenges on the Spacecraft Element, Avoiding a Potential Launch Site Conflict

In the summer of 2017, the JWST project conducted a schedule risk assessment that showed that the October 2018 launch readiness date was unachievable, primarily due to the various components of spacecraft element integration taking longer to complete than planned. The project performed the schedule risk assessment in order to provide ESA a desired launch window about one year prior to the expected launch date. The assessment took into account remaining work to be completed, lessons learned from environmental testing, and the current performance rates of integrating the spacecraft element. As a result of the assessment, in September 2017 NASA requested from ESA a launch window of March 2019 to June 2019. The requested launch window represents a 5- to 8-month delay from the previously planned October 2018 launch readiness date.

The schedule risk assessment incorporated input from Northrop Grumman on expected durations for remaining spacecraft and observatory level integration activities. However, the project's analysis determined that the expected durations provided by Northrop Grumman were overly optimistic. As a result, the project incorporated uncertainty factors into the analysis, which added 2 to 3 months to the schedule. The project also estimated an additional 5 to 8 weeks would be needed because of emerging technical issues not specifically accounted for by the schedule risk assessment. Additionally, the project updated the expected time required at the launch site for processing activities and added about 1.25 months. According to project officials, the confidence in the launch window identified is in line with that of a typical NASA JCL at 70 percent. NASA's independent Standing Review Board reviewed the assessment and found that it was a thorough approach for reviewing the schedule, risks, and uncertainties and that the new proposed launch readiness range is technically feasible with reasonable risk.

NASA's request for a March to June 2019 launch window was driven by its own schedule and technical issues, but also avoids potential conflicts with other mission launches. Regardless of JWST's launch readiness, and prior to undertaking the schedule risk assessment, the project learned in November 2016 of potential scheduling conflicts at the launch site in French Guiana. After numerous delays, BepiColombo, a joint ESA/Japan Aerospace Exploration Agency mission to Mercury, is currently forecasted to have an October 2018 launch readiness date. According to program officials, that mission could have taken precedence over JWST given that planetary missions generally have more limited launch windows. Additionally, Arianespace, a commercial company, currently has a commercial launch scheduled for the December 2018 timeframe.

JWST Project Consumed all of its Planned Schedule Reserve to Address Technical Challenges

While much progress has been made since we last reported in December 2016, the project and Northrop Grumman consumed the remaining 6 months of schedule reserves established at the 2011 replan to address technical challenges that arose during the OTIS and the spacecraft element integration and test work, as well as additional challenges identified by the schedule risk assessment. Specifically:

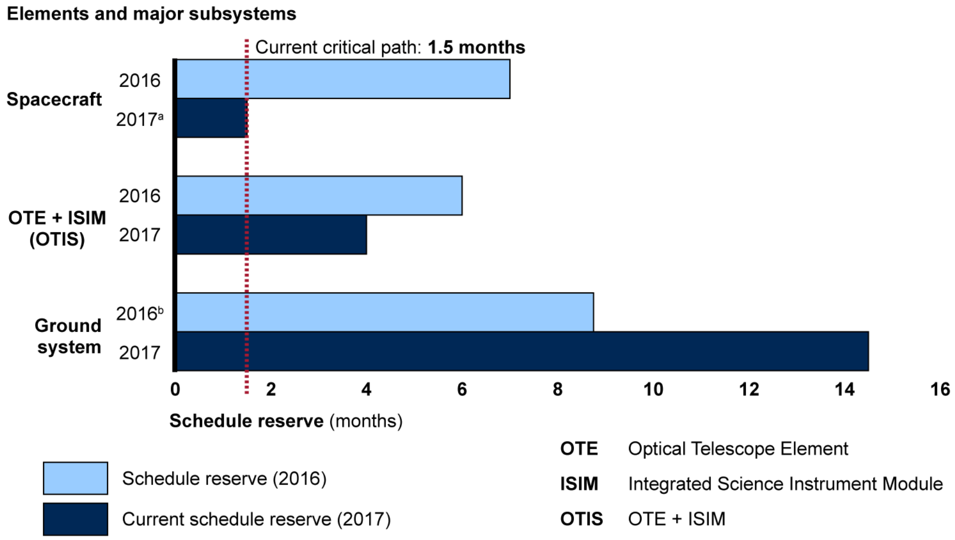
- In February 2017, a vibration anomaly during OTIS vibration testing at Goddard Space Flight Center, occurring in parallel with spacecraft and sunshield issues, consumed 1.25 months and delayed the start of cryovacuum testing, the final event in the OTIS integration and test phase, by several weeks.
- In April 2017, spacecraft and sunshield issues consumed an additional 1.25 months. Specifically, a contractor technician applied too much voltage and irreparably damaged the spacecraft's pressure transducers, components of the propulsion system, which help monitor spacecraft fuel levels. The transducers had to be replaced and reattached in a complicated welding process. At the same time, Northrop Grumman also addressed several challenges with

integrating sunshield hardware such as the mid-boom assemblies and membrane tensioning system, which help deploy the sunshield and maintain its correct shape.

- Finally, in September 2017, the remaining 3.5 months of previously planned schedule reserves was consumed as a result of the contractor having underestimated the time required to complete integration and test work on the spacecraft and other risks identified in the schedule risk analysis. Specifically, execution of spacecraft integration and test tasks, due to the complexity of work and cautious handling given sensitivity of flight hardware, was slower than planned. For example, the installation of numerous membrane retention devices slowed the pace of the work. According to Northrop Grumman officials, the sunshield is elevated off the ground for installation work and the size and quantity of the work lifts necessary for the technicians to access the sunshield requires more maneuvering and prevents the technicians from working on the forward and aft sunshield assemblies simultaneously.

Taking into account the consumption of planned reserves and the establishment of the revised launch window, the project expected to have up to 4 months of schedule reserve extending to the end of the launch window range, or June 2019. However, shortly after the project notified ESA of the launch delay in September 2017, the project received updated information from Northrop Grumman and determined that up to 3 months of schedule reserve would be needed based upon lessons learned from Northrop Grumman's initial sunshield folding operation and implications for remaining deployment test activities. After incorporating some schedule efficiencies, the project now has 1.5 months of schedule reserve remaining. This level of schedule reserve is below the standards established by Goddard Space Flight Center for a project at this stage of development. The project is working with Northrop Grumman to determine if any further schedule reserve can be regained by incorporating schedule efficiencies and adjusting integration and test plans. As shown in the figure below, Northrop Grumman's work on the spacecraft element remains on the project's critical path—the schedule with the least amount of reserve, which determines the overall schedule reserve for the project—now with an estimated 1.5 months of schedule reserve to the end of the launch window in June 2019.

Figure 5: Schedule Reserve Held by Elements and Major Subsystems for the James Webb Space Telescope in 2016 and 2017



Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-18-273

[a]In 2017, the spacecraft was integrated with the sunshield to form the spacecraft element.

[b]Ground system schedule as reported in February 2017.

Ongoing Spacecraft Integration and Test Issues, Challenging Remaining Work, and Slow Contractor Performance Make Additional Launch Delays Likely

Given several ongoing technical issues, and the work remaining to test the spacecraft element and complete integration of the telescope and spacecraft, combined with continuing slower than planned work at Northrop Grumman, we believe that the rescheduled launch window is likely unachievable. For example, in May 2017, Northrop Grumman found that 8 of 16 valves in the spacecraft propulsion system's thruster modules were leaking beyond allowable levels. The project and Northrop Grumman were unable to definitively isolate the root cause of the leaks; however, Northrop Grumman determined that the most likely cause is a handling error at their facility. Specifically, the material around the valves deteriorated due to a solvent used for cleaning. All of the thruster modules were returned to the vendor for investigation and refurbishment. According to project officials, the refurbished thruster modules were returned to the contractor facility in late 2017 for reattachment. However, reattaching the repaired modules is a challenge because of the close proximity of electronics and other concerns. The project included about one month in the schedule risk assessment to account for the time spent investigating and determining the path forward for the thruster issue;

however, the full schedule impact of reattaching the thruster modules to the spacecraft element had not yet been determined and was not incorporated into the analysis. In November 2017, the project and Northrop Grumman chose a reattachment method that project officials stated is expected to require less time to complete and pose fewer risks to the hardware than a traditional welding approach.

In October 2017, when conducting folding and deployment exercises on the sunshield, Northrop Grumman discovered several tears in the sunshield membrane layers. According to program officials, a workmanship error contributed to the tears. The tears can be repaired; however, some schedule reserve may be required to repair them. Additionally, during the deployment exercise, one of the sunshield's six membrane tensioning systems experienced a snag. Northrop Grumman is planning to implement a slight design modification to prevent the issue from occurring again. Northrop Grumman officials have not yet determined if the schedule will be affected as a result.

Beyond mitigating the specific spacecraft thruster module valve leak and sunshield issues, the project faces significant work ahead, and numerous risks remain to be mitigated to acceptable levels. For example, the project and Northrop Grumman must:

- Resolve lingering technical issues from the OTIS cryovacuum test and prepare and ship OTIS to the Northrop Grumman facility in California for integration with the spacecraft.
- Complete integration of spacecraft hardware, and conduct spacecraft element environmental tests and remaining deployments of the spacecraft and sunshield—activities which, to date, have taken considerably longer than planned.
- Integrate the completed OTIS element with the spacecraft element and test the full observatory in the fifth and final integration phase, which includes another set of challenging environmental tests.
- Mitigate approximately 47 remaining tracked hardware and software risks to acceptable levels and continue to address the project's 300+ potential single point failures to the extent possible.
- Prepare and ship the observatory to the launch site and complete final launch site processing, including installation of critical release mechanisms.

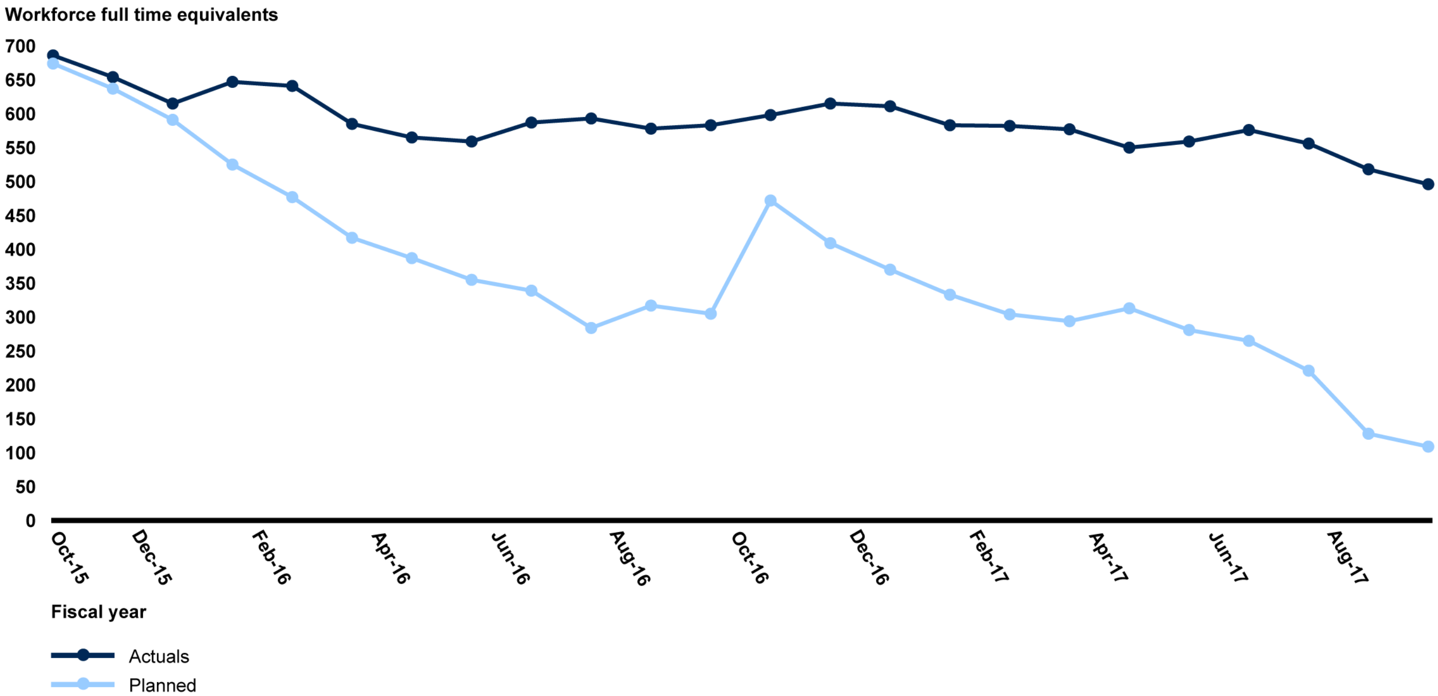
Project officials have expressed concern with Northrop Grumman's ability to prevent further schedule erosion as the project moves through remaining integration and test work. With the project's current low level of schedule reserves, even a relatively minor disruption could cause the project to miss its revised launch window. According to program officials, the contractor has increased its daily work shifts from two to three and is now working 24 hours per day on spacecraft integration, which further limits schedule flexibility. In early 2018, the project's independent Standing Review Board will review the latest schedule inputs based on updated knowledge about spacecraft integration and test activity durations. For example, according to project officials, by early 2018, the contractor is expected to have completed the second of four planned fold and stow sequences on the sunshield, which will provide more insight into whether the current planned schedule is realistic. The Standing Review Board will also examine the project's plans for schedule efficiencies and potential integration and test adjustments to determine if the June 2019 launch window can be met. Project officials stated that following this review, NASA senior management will be briefed on the Standing Review Board's findings and will then formally identify a new launch readiness window.

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 uniquely complex project such as JWST, this risk is magnified. Now that the project is well into its complex integration and test efforts, events are sequential in nature and there are fewer opportunities to mitigate issues in parallel. Since the replan, the project has used about 2.5 months of schedule reserve per year to address technical issues, but, as discussed above, it now has only approximately 1.5 months of schedule reserve to last until the end of the revised launch window in June 2019. Thus, past experience with technical issues in earlier integration phases suggests that this amount of reserve will not be adequate for the challenging work ahead, and further delays to launch readiness are likely. We will continue to monitor the project's progress in meeting its revised schedule as more information is available during this critical integration and test phase.

Higher Contractor Workforce Levels to Address Continuing Technical Challenges Places JWST at Risk of Exceeding Cost Commitments

Northrop Grumman continued to maintain higher than planned workforce levels in the past year and, as a result, NASA will have limited cost reserves to address future challenges. Northrop Grumman's ability to control costs and decrease its workforce is central to JWST's capacity to meet its long-term cost commitments. For the past 44 months, Northrop Grumman's actual workforce has exceeded its projections and the company is not expected to significantly reduce its workforce until the spring of 2019, when NASA plans to ship the completed observatory to the launch site. Northrop Grumman had planned to reduce its workforce in fiscal years 2016 and 2017 as work was planned to be completed, but has needed to maintain higher workforce levels due to technical challenges and the work taking longer than expected. Figure 6 illustrates the difference between the workforce levels that Northrop Grumman projected for fiscal years 2016 and 2017, and its actual workforce levels during that period.

Figure 6: Northrop Grumman Workforce Levels in Fiscal Years 2016 and 2017, Projections at Beginning of Each Fiscal Year versus Actuals



Source: GAO analysis of contractor data. | GAO-18-273

Note: New projections were made at the start of each fiscal year. At the start of fiscal year 2017, in October 2016, new projections were made for the fiscal year resulting in a spike in projected workforce levels.

As shown in figure 6, Northrop Grumman has slightly reduced its workforce since the beginning of fiscal year 2016. However, staffing levels remain higher than projected as a result of previously noted technical challenges including spacecraft and sunshield integration and test challenges, to keep specialized engineers available when needed during final assembly, and to complete required testing activities. Projections made at the beginning of fiscal year 2017—when the expected launch readiness date was October 2018—expected workforce levels to begin at 472 full-time equivalent staff and drop to 109 at the end of the fiscal year. However, technical challenges and delays in completing scheduled work did not allow for the planned workforce reduction and Northrop Grumman reported 496 full-time equivalent staff in September 2017, or 387 more than planned. According to JWST project officials and similar to previous years, Northrop Grumman's priority for fiscal year 2018 is to maintain schedule in order to ensure that the new launch window set from March to June 2019 can be met. As a result, Northrop Grumman's contractor workforce levels are expected to continue to be elevated through JWST's final integration and test phase in fiscal year 2019 where the spacecraft and OTIS will be integrated before shipment to the launch site.

Northrop Grumman submitted a cost overrun proposal to NASA in July 2016, primarily to address costs associated with sustaining its workforce at higher levels than planned in fiscal year 2017. An overrun proposal seeks to increase the value of a cost-reimbursement contract when the total estimated cost is less than the contract's estimated cost to complete the performance of the contract.[12] In addition to higher workforce levels, the overrun proposal replenished contractor management reserves that had been used to address technical issues, and addressed projected growth in the contractor's cost to complete work. NASA and the contractor completed negotiations in September 2017 and executed a contract modification that added $179.9 million to the value of the contract to cover Northrop Grumman's cost overrun and additional negotiated items, such as particle dampers.[13] This amount was intended to cover the cost of the remaining work through the expected launch date of October 2018. However, by September 2017 Northrop Grumman had no remaining schedule reserves and a limited amount of cost reserves with which to address future costs.

Furthermore, the project determined—as discussed above—that the October 2018 launch window was not feasible and established a new launch window. According to JWST project officials, the project expects to issue a request for proposal in early 2018 to cover the costs for the remaining work through the new launch window. The project plans to use a significant portion of fiscal years 2018 and 2019 program cost reserves to address Northrop Grumman costs and unanticipated technical challenges. According to JWST program officials, if the contractor does not improve its schedule efficiency, the remaining reserves will be used to offset increased cost resulting from taking longer to complete the work.

[12]JWST's contract with Northrop Grumman is a cost-plus-award-fee contract. Award fees are used when key elements of performance cannot be defined objectively, and, as such, require the project officials' judgment to assess contractor performance.

[13]Particle dampers provide a mechanism for diverting energy away from resonant structural vibrations of the observatory during launch.

For the sixth consecutive year, the JWST project managed spending within its allocated budget in fiscal year 2017. However, JWST is still resolving technical challenges and planned work continues to take longer to complete. Prudent management of its resources allowed the project to carry into fiscal year 2018 about a third more carry over funding than it had projected at the beginning of the fiscal year. Program officials said that assuming the remaining integration and tests proceed as planned and no long delays are encountered, the existing program resources accommodate the new launch window of March to June 2019. The project continues to identify funding options in the event of a delay of beyond the end of the launch window. Under the 2011 replan, Congress placed an $8 billion cap on formulation and development costs, but any long delays beyond the new launch window—which, as noted above, are likely—place the project at risk of exceeding this cap.

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 is available at no charge on GAO's website and http://www.gao.gov.

If 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 key contributions to this report are listed in appendix II.

Cristina T. Chaplain
Director
Contracting and National Security Acquisitions

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Committee on Appropriations
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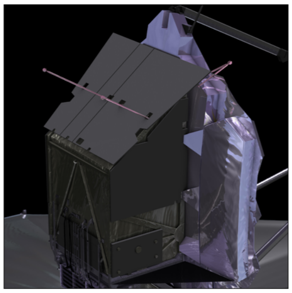
The Honorable Lamar Smith
Chairman
The Honorable Eddie Bernice Johnson
Ranking Member
Committee on Science, Space and Technology
House of Representatives

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

Figure 7: Elements and Major Subsystems of the James Webb Space Telescope (JWST) Observatory



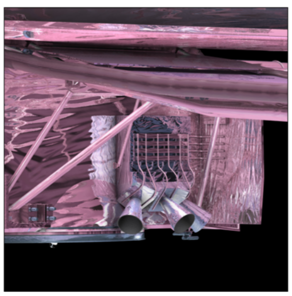
Integrated Science Instrument Module
Acronym: ISIM
Contractor/Center: Goddard Space Flight Center
Description: Combines the 4 instruments

Mid Infrared Instrument
Acronym: MIRI
Contractor/Center: Jet Propulsion Lab and European Consortium
Description: Science instrument

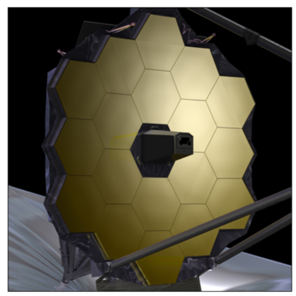
Near Infrared Spectrograph
Acronym: NIRSpec
Contractor/Center: European Space Agency
Description: Science instrument

Fine Guidance Sensor / Near-Infrared Imager and Slitless Spectrograph
Acronym: FGS/NIRISS
Contractor/Center: Canadian Space Agency
Description: Telescope guider and Science instrument

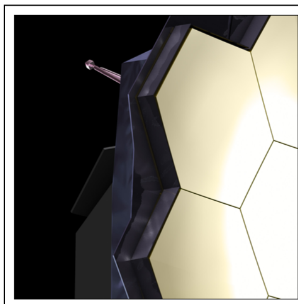
Near Infrared Camera
Acronym: NIRCam
Contractor/Center: University of Arizona
Description: Science instrument and Wave Front Sensor



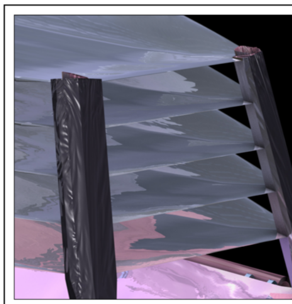
Spacecraft
Contractor/Center: Northrop Grumman Aerospace Systems
Description: Contains the power, communications, and avionics needed to operate the observatory. Contains the cryocooler needed to achieve MIRI operational temperatures approximating 6.7 Kelvin



Optical Telescope Element
Acronym: OTE
Contractor/Center: Northrop Grumman Aerospace Systems
Description: 18 primary mirror segments, secondary mirror, tertiary mirror, backplane support structure



Optical Telescope & Integrated Science Instrument Module
Acronym: OTIS (**OTE**+**IS**IM)
Contractor/Center: Goddard Space Flight Center
Description: Hardware configuration created when OTE and ISIM are integrated



Sunshield
Contractor/Center: Northrop Grumman Aerospace Systems
Description: Tennis court sized series of 5 thin membranes, provides passive cooling to achieve operational temperatures approximating 45 Kelvin for the OTE and ISIM

Sources: GAO (analysis); National Aeronautics and Space Administration (NASA) (data and images). | GAO-18-273

Appendix II: GAO Contact and Staff Acknowledgments

GAO Contact

Cristina T. 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); Brian Bothwell, Laura Greifner, Daniel Kuhn, Katherine Lenane, Jose Ramos, Carrie Rogers, Sylvia Schatz, and Roxanna Sun made key contributions to this report.

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