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Report to Congressional Committees

March 2019

JAMES WEBB SPACE TELESCOPE

Opportunity Nears to Provide Additional Assurance That Project Can Meet New Cost and Schedule Commitments

Accessible Version

GAO-19-189

GAO Highlights

Highlights of GAO-19-189, a report to congressional committees

Why GAO Did This Study

JWST, a large, deployable telescope, is one of NASA's most complex projects and top priorities. The project has delayed its planned launch three times since September 2017 due to problems discovered in testing. In June 2018, NASA approved new cost and schedule estimates for JWST. Since the project established its cost and schedule baselines in 2009, the project's costs have increased by 95 percent and the launch date has been moved back by 81 months.

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 seventh report. This report assesses (1) the considerations NASA took into account when updating the project's cost and schedule commitments and (2) the extent to which NASA has taken steps to improve oversight and performance of JWST, among other issues. GAO reviewed relevant NASA policies, analyzed NASA and contractor data, and interviewed NASA and contractor officials.

What GAO Recommends

GAO recommends NASA update the project's joint cost and schedule confidence level analysis. NASA concurred with the recommendation made in this report.

View GAO-19-189. For more information, contact Cristina Chaplain at (202) 512-4841 or chaplainc@gao.gov.

March 2019

JAMES WEBB SPACE TELESCOPE

Opportunity Nears to Provide Additional Assurance That Project Can Meet New Cost and Schedule Commitments

What GAO Found

In June 2018, the National Aeronautics and Space Administration (NASA) revised the cost and schedule commitments for the James Webb Space Telescope (JWST) to reflect known technical challenges, as well as provide additional time to address unanticipated challenges. For example, the revised launch readiness date of March 2021 included 5.5 months to address a design issue for the cover of the sunshield (see image). The purpose of the sunshield is to protect the telescope's mirrors and instruments from the sun's heat. NASA found that hardware on the cover came loose during testing in April 2018. The new cost estimate of $9.7 billion is driven by the schedule extension, which requires keeping the contractor's workforce on board longer than expected.

Technicians and Engineers Lay Sunshield Layers Flat for Inspection in the Northrop Grumman Clean Room

Source: Northrop Grumman Aerospace Systems. | GAO-19-189

Before the project enters its final phase of integration and test, it must conduct a review to determine if it can launch within its cost and schedule commitments. As part of this review, the project is not required to update its joint cost and schedule confidence level analysis—an analysis that provides the probability the project can meet its cost and schedule commitments—but government and industry cost and schedule experts have found it is a best practice to do so. Such analysis would provide NASA officials with better information to support decisions on allocating resources, especially in light of the project's recent cost and schedule growth.

NASA has taken steps to improve oversight and performance of JWST, and identified the JWST project manager as responsible for monitoring the continued implementation of these changes. Examples of recent changes include increasing on-site presence at the contractor facility and conducting comprehensive audits of design processes. Sustaining focus on these changes through launch will be important if schedule pressures arise later and because of past challenges with communications. GAO will follow up on the project's monitoring of these improvements in future reviews.

Contents

Letter 1

Background 4
NASA Revised Schedule and Cost Commitments to Reflect Prior and Ongoing Technical Challenges 13
Project Has Used Some Schedule Reserve from Its 2018 Replanned Schedule with Challenging Integration and Test Work Remaining 20
NASA Is Augmenting Oversight of Contractor and Project Performance, and Identified the JWST Project Manager as Responsible for Sustaining Changes 26
Conclusions 30
Recommendation for Executive Action 30
Agency Comments and our Evaluation 31

Appendix I: Elements and Major Subsystems of the James Webb Space Telescope (JWST) Observatory 34

Appendix II: Comments from the National Aeronautics and Space Administration 36

Appendix III: GAO Contact and Staff Acknowledgments 38

Appendix IV: Accessible Data 39

Data Tables 39
Agency Comment Letter 39

Tables

Table 1: Examples of Changes to Oversight of Contractor and Project Performance after James Webb Space Telescope Schedule Delays in 2018 26
Table 2: Positions Responsible for Aspects of James Webb Space Telescope (JWST) Oversight and Performance 28

Figures

Figure 1: James Webb Space Telescope 6
Figure 2: History of Changes to the James Webb Space Telescope Project's Cost and Schedule 11

Figure 3: Membrane Cover Assembly Being Repaired at Contractor's Facility 15
Figure 4: James Webb Space Telescope Integration and Test (I&T) Schedule and the Distribution of Schedule Reserves as of July 2018 17
Figure 5: Estimated Workforce Required to Finish Assembling and Operating James Webb Space Telescope 19
Figure 6: James Webb Space Telescope Membrane Cover Assembly (MCA) Repairs Schedule and Use of Schedule Reserves 21
Figure 7: James Webb Space Telescope Primary Mirror and Frill 22
Figure 8: Optical Telescope Element and Integrated Science Instrument Module (OTIS) and Spacecraft Element Together in Northrop Grumman Clean Room 24
Figure 9: Elements and Major Subsystems of the James Webb Space Telescope (JWST) Observatory 35
Accessible Data for Figure 5: Estimated Workforce Required to Finish Assembling and Operating James Webb Space Telescope 39

Abbreviations

IRB	Independent Review Board
I&T	integration and test
ISIM	Integrated Science Instrument Module
JCL	Joint Cost and Schedule Confidence Level
JWST	James Webb Space Telescope
MCA	Membrane Cover Assembly
NASA	National Aeronautics and Space Administration
OTE	Optical Telescope Element
OTIS	Optical Telescope Element and Integrated Science Instrument Module

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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.[1] 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 development challenges. The project has experienced significant cost and schedule growth in recent years due to problems discovered during integration and testing. In June 2018, NASA approved new cost and schedule commitments for JWST with a cost of $9.7 billion and a launch readiness date of March 2021. This represents a total of 95 percent of cost growth and 81 months of schedule delays since the project's cost and schedule baselines were first established in 2009.

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.[2] This report is our seventh in response to that provision. For this report, we assessed (1) the considerations that NASA took into account when updating the JWST project's cost and schedule commitments, (2) the technical and integration challenges, if any, that are affecting the execution of the JWST project, and (3) the extent to which NASA has taken steps to improve oversight and performance of the JWST project.

[1]NASA classifies JWST as a single-project program—those which tend to have long development and operational lifetimes and represent a large investment. The JWST program office is based at NASA headquarters, and the project office is based at Goddard Space Flight Center. The terms "program" and "project" are used interchangeably throughout this report.

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

To address these objectives, we examined the schedule, technical, and cost performance of the project since our last report in February 2018.[3] To determine the considerations that NASA took into account when updating the JWST project's cost and schedule commitments, we analyzed the JWST project's proposed changes to its 2011 rebaseline.[4] We compared the project's prior cost and schedule baseline to the project's new cost and schedule estimates to determine what changes were made, including changes to workforce projections. In addition, we compared the process the project used to update cost and schedule estimates with NASA guidance and policies on updating cost and schedule estimates and best practices identified in GAO's Cost Estimating and Assessment Guide.[5] We discussed the project's cost and schedule estimates from the 2018 replan with NASA, Northrop Grumman Aerospace Systems (Northrop Grumman), and the James Webb Space Telescope Independent Review Board (IRB) and interviewed officials within the Office of the Chief Financial Officer on relevant NASA guidance.

To assess the extent to which technical challenges and integration risks are affecting the execution of the JWST project, we reviewed project and contractor schedule documentation to identify the progress made and any challenges faced since our last report in February 2018.[6] We examined monthly project status reports to management to monitor schedule reserve levels and usage, identify potential risks and technical challenges

[3]GAO, *James Webb Space Telescope: Integration and Test Challenges Have Delayed Launch and Threaten to Push Costs Over Cap,* GAO-18-273 (Washington, D.C.: Feb. 28, 2018).

[4]A rebaseline is a process initiated if the NASA Administrator determines the development cost growth is more than 30 percent of the estimate provided in the baseline of the report, or if other events make a rebaseline appropriate. A replan is a process generally driven by changes in program or project cost parameters, such as if development cost growth is 15 percent or more of the estimate in the baseline report or a major milestone is delayed by 6 months or more from the baseline's date. A replan does not require a new project baseline to be established. When the NASA Administrator determines that development cost growth is likely to exceed the development cost estimate by 15 percent or more, or a program milestone is likely to be delayed from the baseline's date by 6 months or more, NASA must submit 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. 51 U.S.C §30104(e)(2)(reporting requirement).

[5]GAO, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, GAO-09-3SP (Washington, D.C.: Mar. 2, 2009).

[6]GAO-18-273.

that may affect the project's schedule, and gain insights on the project's progress. We interviewed project officials at Goddard Space Flight Center and contractor officials from Northrop Grumman and the Association of Universities for Research in Astronomy's Space Telescope Science Institute concerning the challenges that have affected schedule, and the project's and contractor's plans to address these challenges. We also discussed what benefits exist, if any, of conducting cost and schedule risk analyses during integration and test with government and industry cost and schedule experts. Further, we attended two project reviews, where project and program officials briefed NASA headquarters officials on the current status of the project. We examined project risks from monthly risk registers to understand the likelihood of occurrence, the potential effect on cost and schedule, and the steps the project plans to take to mitigate the risks. We also requested updates on the status of project risks and top issues that affected technical challenges the project was working to mitigate during the course of our review. We also obtained information on the status of project software and challenges from independent NASA reviewers with NASA's Independent Verification and Validation program.

Finally, to assess the extent to which NASA has taken steps to improve oversight and performance of the JWST project, we reviewed documentation on changes that NASA made to contractor oversight and project oversight activities between April and November 2018. We also reviewed the May 2018 IRB final report. We discussed these changes and the implementation of related IRB recommendations with Goddard Space Flight Center and NASA headquarters project officials; Northrop Grumman and Space Telescope Science Institute contractor officials; IRB members; and Defense Contract Management Agency officials who are responsible for providing oversight of software and quality assurance processes at the Northrop Grumman facility on behalf of NASA. In addition, we reviewed project and Northrop Grumman documentation that described or tracked changes to oversight and implementation of IRB recommendations. We also reviewed award fee documentation to examine NASA's determination of the percentage of the available award fee Northrop Grumman earned in two award fee periods—April 1, 2017 to September 30, 2017 and October 1, 2017 to March 31, 2018. These award fee periods are inclusive of the time period in which NASA first started identifying that additional schedule slips would be likely. We compared the findings and recommendations of a 2010 independent review report to the 2018 independent review report to determine whether there were similar findings or recommendations. Further, we discussed challenges of workmanship errors and steps projects and companies can take to avoid them with an expert on quality in NASA's Office of Safety and Mission Assurance and experts at the Aerospace Corporation.

Our work was performed primarily at NASA headquarters in Washington, D.C.; Goddard Space Flight Center in Greenbelt, Maryland; and Northrop Grumman Corporation in Redondo Beach, California. We met with officials from the Space Telescope Science Institute in Baltimore, Maryland, which will be responsible for operating the observatory on behalf of NASA, among other things. We also obtained information from officials at the Independent Verification and Validation facility in Fairmont, West Virginia. This facility is responsible for providing independent review of project safety and mission critical software.

We conducted this performance audit from April 2018 to March 2019 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.

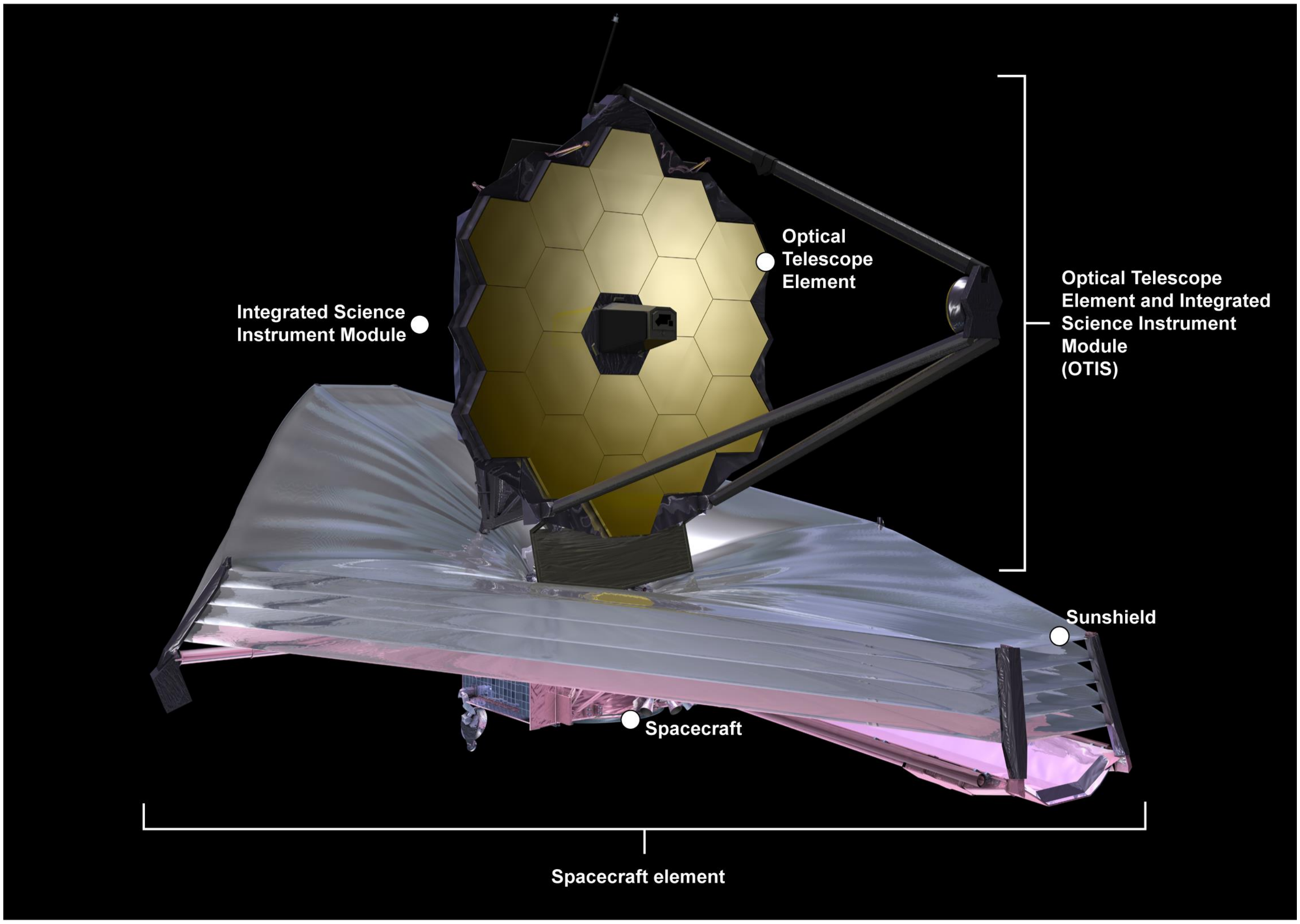
Background

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).[7] The hardware configuration referred to as OTIS was created when the Optical Telescope Element and the Integrated Science Instrument Module were integrated. 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 the elements and major subsystems of JWST and appendix 1 for more details, including a description of the elements, major subsystems, and JWST's instruments.

[7]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.

Figure 1: James Webb Space Telescope



Sources: GAO (analysis); National Aeronautics and Space Administration (NASA) (data and images). | GAO-19-189

For the majority of work remaining, the JWST project is relying on two contractors: Northrop Grumman and the Association of Universities for Research in Astronomy's Space Telescope Science Institute. 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. Space Telescope Science Institute'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, the Institute 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 found that complex development efforts like JWST face numerous risks and unforeseen technical challenges, which can often become apparent during integration and testing.[8] To accommodate unanticipated challenges and manage risk, projects reserve extra time in their schedules, which is referred to as schedule reserve, and extra funds 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.

Cost reserves are additional funds within the project manager's budget that can be used to address unanticipated issues for any element or

[8] 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) 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).

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—the NASA center with responsibility for managing JWST—has issued procedures that establish the requirements for cost and schedule reserves.[9] In addition to cost reserves held by the project manager, management reserves are funds held by the contractors that allow them to manage program risks and to address unanticipated cost increases throughout development. We have previously 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.[10]

JWST's Use of Award Fees

NASA's cost-plus-award-fee contract with Northrop Grumman has spanned almost two decades, during which there have been significant variances in contractor performance. Cost-reimbursement contracts are suitable when uncertainties in the scope of work or cost of services prevent the use of contract types in which prices are fixed, known as fixed-price contracts.[11] Award fee contracts provide contractors the opportunity to obtain monetary incentives for performance in designated areas identified in the award fee plan. Award fees may be used when key elements of performance cannot be defined objectively, and, as such, require the project officials' judgment to assess contractor performance. For JWST's contract with Northrop Grumman, these areas include cost, schedule, technical, and business management and are established in the contracts' performance evaluation plans.

[9]NASA, Goddard Procedural Requirements 7120.7A, *Schedule and Budget Margins for Flight Projects* (Feb. 28, 2017); Goddard projects are required to baseline a minimum of 2 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 20 percent or higher at the start of the system-level integration and test phase.

[10]GAO, *NASA: Earned Value Management Implementation across Major Spaceflight Projects Is Uneven*, GAO-13-22 (Washington, D.C.: Nov. 19, 2012); and GAO-09-3SP.

[11]Cost reimbursement contracts provide for payment of allowable incurred costs, to the extent prescribed in the contract. FAR 16.301-1.

In December 2013, the JWST program and the contractor agreed to replace a $56 million on-orbit incentive—incentives based on successful performance in space—with award fees. The award fees are to incentivize cost and schedule performance during development.[12] This shift increased the available award fee for the entire contract to almost a quarter of a billion dollars. According to officials, restructuring the incentives gave NASA more flexibility to incentivize the contractor to prioritize the cost and schedule performance over exceeding technical requirements. In December 2014, we found that NASA award fee letters of award fee periods from February 2013 to March 2014 indicated that the contractor had been responsive to interim award fee period criteria provided by NASA and that contractor officials confirmed that they pay close attention to this guidance in prioritizing their work.[13] For example, Northrop Grumman officials reported that they had made specific changes to improve communications in direct response to this guidance, which was validated by award fee letters from NASA.

History of Cost Growth and Schedule Delays

The JWST program has a history of significant schedule delays and increases to project costs, which resulted in replans in 2011 and 2018. Before 2011, early technical and management challenges, contractor performance issues, low levels of cost reserves, and poorly phased funding caused the JWST program to delay work. As a result, the program experienced schedule overruns, including launch delays, and cost growth.[14] The JWST program underwent a replan in September 2011, and a rebaseline in November of that same year, and 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.

Congress also required that NASA treat any cost increase above the cap according to procedures established for projects that exceed their development cost estimates by at least 30 percent. This process is known

[12]GAO, *James Webb Space Telescope: Project Facing Increased Schedule Risk with Significant Work Remaining,* GAO-15-100 (Washington, D.C.: Dec. 15, 2014).

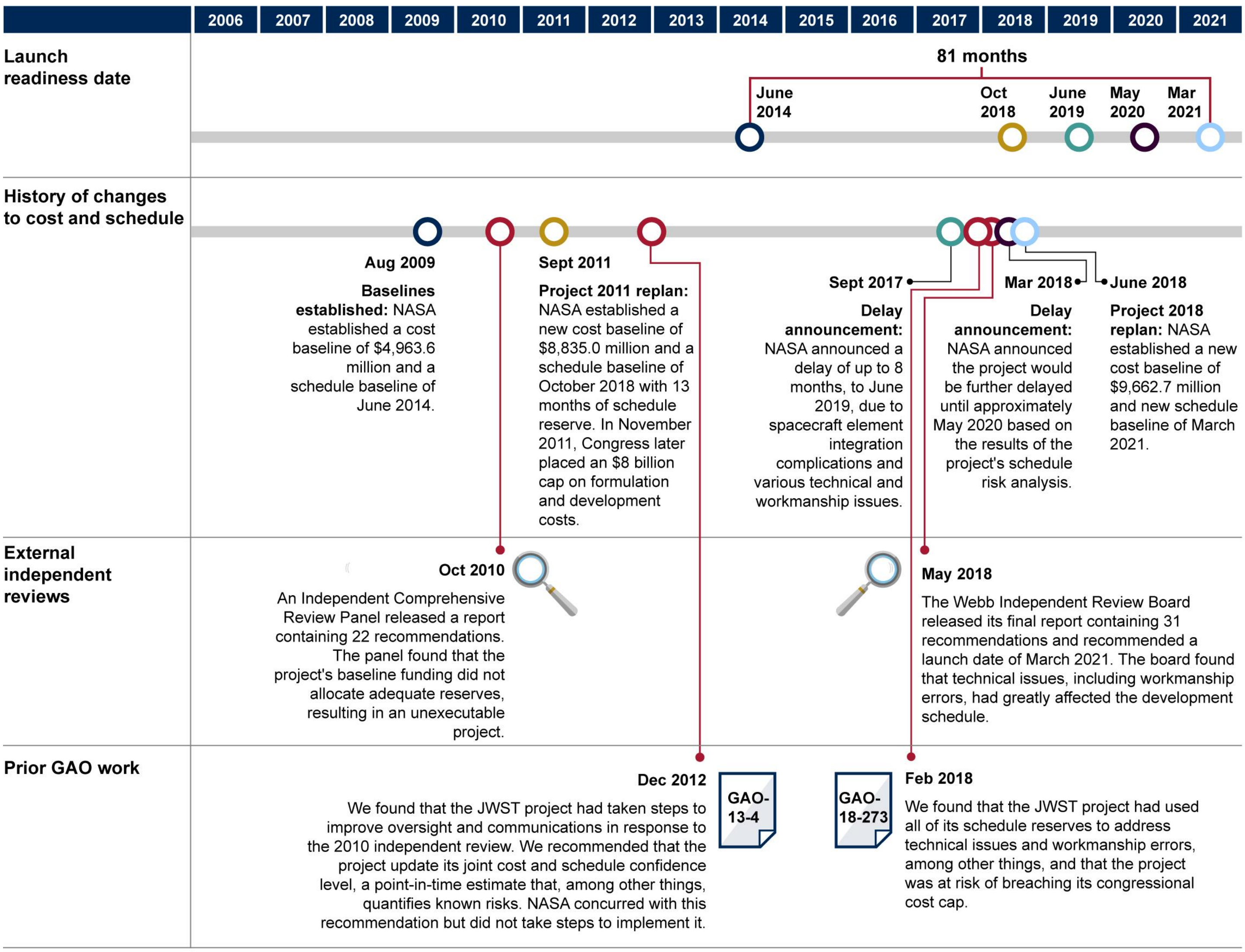
[13]GAO-15-100.

[14]GAO-18-273.

as a rebaseline. Congress must authorize continuation of the JWST program if formulation and development costs increase over the $8 billion cost cap.

In June 2018, after a series of launch delay announcements due to technical and workmanship issues identified during spacecraft element integration, NASA notified Congress that it had again revised the JWST program's cost and schedule estimates. NASA estimated that it now required $828 million in additional resources and 29 more months to complete beyond those estimates agreed to in the 2011 rebaseline. As of November 2018, NASA had funding to continue to execute the program and was waiting to see if Congress would authorize the program's continuation and appropriate funds for the program in fiscal year 2019. Figure 2 shows the project's history of changes to its cost or schedule and key findings from two external independent review teams and our prior work.

Figure 2: History of Changes to the James Webb Space Telescope Project's Cost and Schedule



Source: GAO analysis of National Aeronautics and Space Administration (NASA) documents, external independent review documents, and prior GAO reports. | GAO-19-189

As discussed above, various technical and workmanship errors drove some of the more recent delays.[15] Examples of some of the workmanship issues we found in the past include:

- 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 April 2017, a contractor technician applied too much voltage and irreparably damaged the spacecraft's pressure transducers, components of the propulsion system that 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. These issues combined took up another 1.25 months of schedule reserve.
- In May 2017, some of the valves in the spacecraft propulsion system's thruster modules were leaking beyond permissible levels. Northrop Grumman determined that the most likely cause was the use of an improper cleaning solution, and the thruster modules were returned to the vendor for investigation and refurbishment. Reattaching the refurbished modules was expected to be complete by February 2018, but was delayed by one month when a technician applied too much voltage to one of the components in a recently refurbished thruster module. NASA and Northrop Grumman reported that resolving the thruster module issue resulted in a 2-month delay to the project's overall schedule.
- 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 resulted in another 2-month delay to the project's overall schedule.

In addition, some first-time efforts took longer than planned. For example, in fall 2017, the project determined that it would need to use up to 3 months of schedule reserve based upon lessons learned from the contractor's initial sunshield folding operation. This first deployment, or unfolding, took 30 days longer than planned. The sunshield has since

[15] GAO-17-71 and GAO-18-273.

undergone another deployment, and will be deployed twice more before launch.

The IRB took into account these technical and workmanship errors, as well as other considerations, when it analyzed the project's organizational and technical issues. The board's final report, issued in May 2018, included 31 recommendations that addressed a range of factors. For example, the IRB recommended that the project:

- Conduct an audit to identify potential embedded design flaws—problems that have not been detected through analysis, inspection, or test activities and pose a significant risk to JWST schedule, cost, and mission success;
- Establish corrective actions to detect and correct human mistakes during integration and test;
- Establish a coherent, agreed-upon, and factual narrative on project status and communicate that status regularly across to all relevant stakeholders; and
- Augment integration and test staff to ensure adequate long-term staffing and improve employee morale.

In its response to the IRB's report, NASA stated that it accepted the report's recommendations and had already begun implementing action in response to many of them. Further, project officials told us that some of the actions were underway before the IRB completed its review.

NASA Revised Schedule and Cost Commitments to Reflect Prior and Ongoing Technical Challenges

To develop a new schedule for JWST's 2018 replan, NASA took into account the remaining integration and test work and added time to the schedule to address threats that were not yet mitigated. This includes 5.5 months to address an anomaly that occurred on the sunshield's cover in 2018. The project also replenished its schedule reserves—which we found in February 2018 had been consumed—so that they now exceed the recommended levels.[16] Both the project and IRB conducted schedule

[16]GAO-18-273.

risk assessments that produced similar launch dates. The project relied on the replan schedule to determine its remaining costs because the workforce necessary to complete the observatory represents most of the remaining cost.

Following is additional information on the schedule and cost considerations.

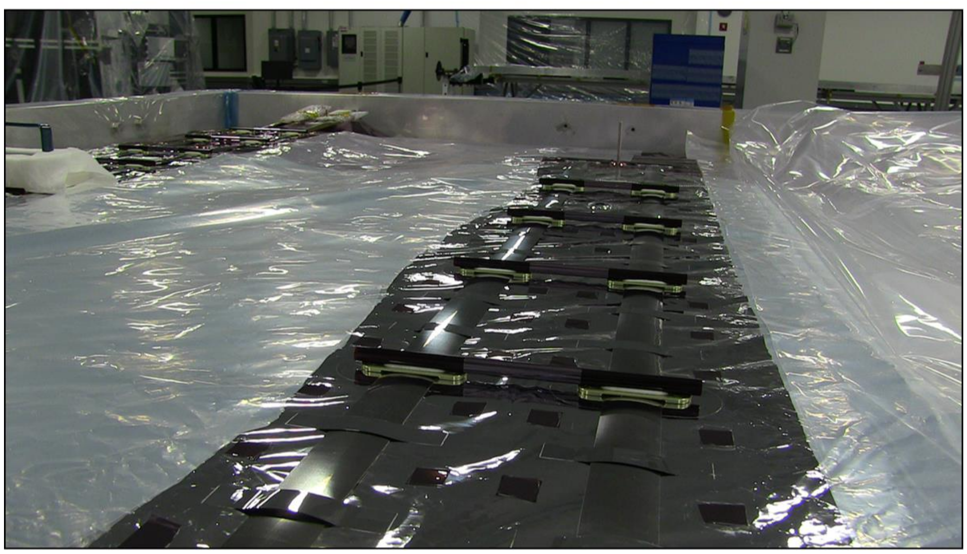
Schedule: JWST's revised launch readiness date of March 2021 reflects a consideration of the hardware integration and test challenges the project has experienced, including adding time to:

- Add snag guards for the membrane tensioning system—which helps deploy the sunshield and maintain its correct shape—to prevent excess cable from snagging,
- Repair tears of the sunshield membrane,
- Deploy, fold, and stow the sunshield, and
- Mitigate contractor schedule threats.

In addition, the project added extra time to the schedule to complete repairs to the membrane cover assembly, which did not perform as expected during acoustics testing in April 2018. The membrane cover assembly shown in figure 3 is used to cover the sunshield membrane when in the stowed position to provide thermal protection during launch.

Figure 3: Membrane Cover Assembly Being Repaired at Contractor's Facility

Membrane cover assembly.



Membrane cover assembly with bumpers.

Source: Northrop Grumman Aerospace Systems. | GAO-19-189

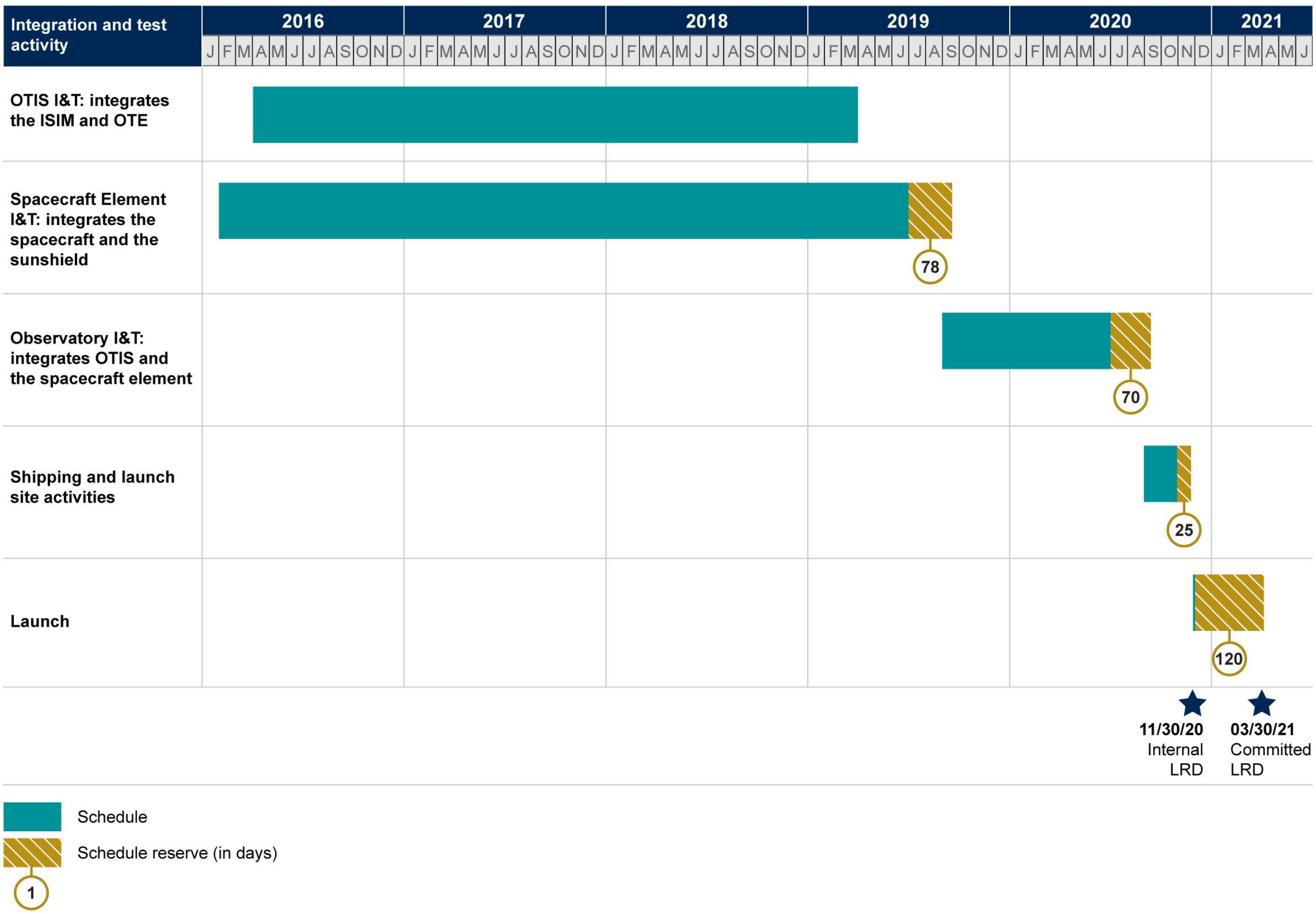
After the anomaly occurred, the project halted spacecraft element testing, investigated the anomaly, and found that the fasteners had come loose due to a design change made to prevent the fasteners from damaging the sunshield membrane. The design change caused the nuts to not lock properly. According to project officials, due to the design of the membrane cover assembly, the project was not able to conduct flight-like, stand-alone testing on the cover prior to spacecraft element testing. As a result, the project did not discover the design issue until the hardware came loose while installed on the spacecraft element. The project determined that the repairs would take approximately 5.5 months.

The project's replan also reflected schedule reserves above the level required by Goddard Space Flight Center policy, which would have been approximately 5 months at that time.[17] The new schedule includes a total of 293 days or 9.6 months of schedule reserves leading up to its committed launch readiness date of March 2021.[18] NASA approved a JWST launch date of March 2021, but the project and the contractor are working toward a launch date in November 2020. Figure 4 shows the project's new schedule following the 2018 replan, including how the project distributed its schedule reserves through different integration and test activities.

[17]NASA, Goddard Procedural Requirements 7120.7A, *Schedule and Budget Margins for Flight Projects* (Feb. 28, 2017).

[18]The project holds 173 days of schedule reserve leading up to its internal launch readiness date of November 2020 and the program at NASA headquarters holds the remaining 120 days of schedule reserve between the internal launch readiness date and the committed launch readiness date of March 2021.

Figure 4: James Webb Space Telescope Integration and Test (I&T) Schedule and the Distribution of Schedule Reserves as of July 2018



LRD = Launch readiness date
ISIM = Integrated Science Instrument Module
I&T = Integration and Test
OTE = Optical Telescope Element
OTIS = OTE + ISIM Integrated

Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-189

As part of its May 2018 study, the IRB reviewed the project's schedule and recommended a launch date of March 2021, which was subsequently reflected in NASA's new schedule for the program. In reviewing the project's schedule, the IRB found that the project had robust scheduling practices for ensuring that the schedule represented a complete and dynamic network of tasks that could respond automatically to changes.

This schedule also passed a standard health check with minimal errors indicating that it was well constructed. However, the IRB noted that this schedule does not account for certain types of unknown risks to the program such as integration and test errors which can take many months to resolve, or the potential need to remove a science instrument from the observatory, which can have about a 1 year impact. As a result, the program could experience additional delays if a risk of this magnitude is realized.

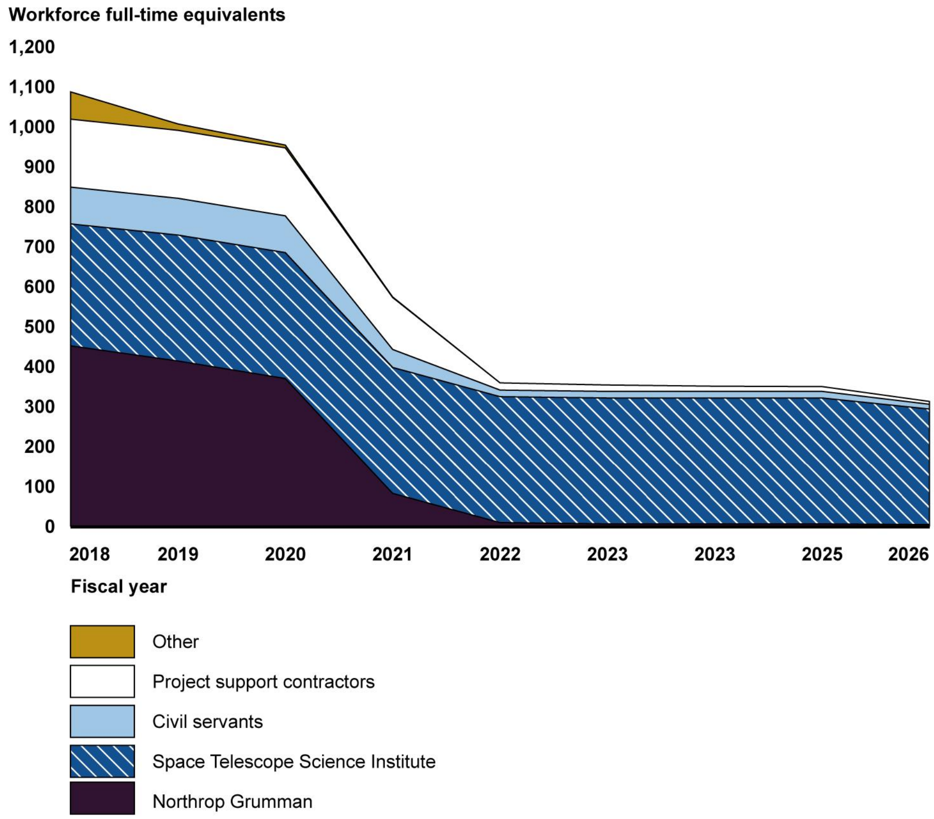
Cost: The project's new $9.7 billion life-cycle cost estimate is principally driven by the schedule extension, which requires keeping the contractor's workforce to complete integration and test longer than expected. Specifically, the project determined that almost all of the hardware had been delivered and the remaining cost was predominantly the cost for the workforce necessary to complete and test the observatory.

For the past 3 years, we have reported that Northrop Grumman's ability to decrease its workforce was central to JWST's capacity to meet its long-term cost commitments.[19] However, Northrop Grumman's actual workforce continued to exceed its projections. This was because it needed to maintain higher workforce levels due to technical challenges, including problems with spacecraft and sunshield integration and test. It also needed to keep specialized engineers available when needed during final assembly and test activities.

In developing the cost estimate supporting the 2018 replan, the project used a Northrop Grumman workforce profile that is higher than previous projections because Northrop Grumman now plans to maintain personnel longer during integration and test. According to project officials, the planned reduction of Northrop Grumman's workforce is now more gradual and conservative than the prior plan. For example, the Northrop Grumman workforce will not start to significantly decline until the observatory ships to the launch site, which is expected to occur in August 2020. As shown in Figure 5, the JWST workforce assembling the observatory declines and the government and contractor workforce necessary to manage and operate the observatory remains after the internal launch readiness date of November 2020.

[19]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), GAO-17-71, and GAO-18-273.

Figure 5: Estimated Workforce Required to Finish Assembling and Operating James Webb Space Telescope



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-189

As seen in the above figure, the Space Telescope Science Institute workforce, the contractor responsible for operating JWST, will remain generally flat between fiscal years 2021 to 2026 when it operates the observatory. The NASA civil service and support contractor will remain relatively flat through November 2020 launch date and then decline. In addition, the new cost estimate also took into account $61 million for implementing the IRB recommendations and mission success enhancements, funding for project cost reserves, and operations costs.

In June 2018, the NASA associate administrator—who is the project's decision authority—approved the project to proceed with its replan with a March 2021 launch date and $9.7 billion in life-cycle costs based on the Agency Program Management Council review and replan documents. The associate administrator did not require the project to conduct an updated Joint Cost and Schedule Confidence Level (JCL) analysis for this replan. A JCL is an integrated analysis of a project's cost, schedule, risk, and uncertainty whose result indicates the probability of a project's success of meeting cost and schedule targets. NASA policy states that a JCL should be recalculated and approved as a part of the rebaselining approval process, but it is not required. In its replan decision memo, NASA's associate administrator explained that he did not require the project to update the JCL because project costs are almost entirely related to the workforce and most of the remaining planned activities will be performed generally in sequence. Therefore, according to NASA's associate administrator, the total cost would be driven almost entirely by the schedule because the workforce levels will remain the same through delivery of the observatory. Both the project and independent estimators used multiple schedule estimating methods to analyze the schedule for the remaining work, and NASA's associate administrator said these analyses returned consistent, high confidence launch dates.

Project Has Used Some Schedule Reserve from Its 2018 Replanned Schedule with Challenging Integration and Test Work Remaining

The project's ability to execute to its new schedule will be tested as it progresses through the remainder of challenging integration and test work. The project has yet to complete three of five integration and test phases. The remaining phases include integration and test of OTIS, the spacecraft element, and the observatory.[20] 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.[21] For a uniquely complex project such as JWST, this risk is magnified as events start to become more sequential in nature. As a result, it will continue to become more difficult for the project to avoid schedule delays by mitigating issues in parallel.

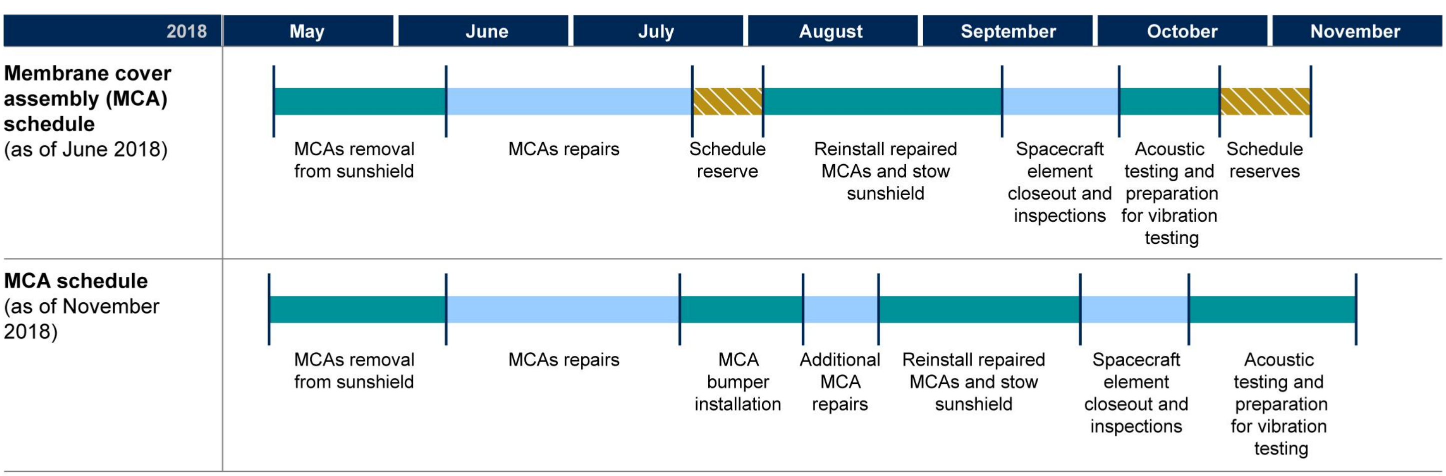
[20]The project and Northrop Grumman completed the Integrated Science Instrument Module and the Optical Telescope Element integration phases in March 2016.

[21]GAO, *Space Launch System: Resources Need to be Matched to Requirements to Decrease Risk and Support Long Term Affordability*, GAO-14-631 (Washington, D.C.: July 23, 2014); *Space Launch System: Management Tools Should Better Track to Cost and Schedule Commitments to Adequately Monitor Increasing Risk,* GAO-15-596 (Washington, D.C.: July 16, 2015); and GAO-16-112.

As of November 2018, the project is about a week behind its replanned schedule because repairs on the membrane cover assembly took longer than planned. Completing the membrane cover assembly repairs and returning the spacecraft to vibration testing was a key event for the project to demonstrate that it could execute to its new schedule. When the project developed its 2018 replanned schedule, it had planned to complete the membrane cover assembly repairs and reinstall the assembly onto the sunshield and restart spacecraft element integration and test activities by November 6, 2018. The project allocated 4 weeks of schedule reserves specifically for these repairs. However, the membrane cover repairs proved more difficult than anticipated. For example, the program had to address unanticipated technical challenges on the membrane cover assemblies, including repairing tears and pin holes in the covers discovered after the covers were removed. The project also had to allot time to install bumpers, which are kapton tubes, to the assembly to protect the composite material on a sunshield structure during launch. The project identified the need to add the bumpers during subassembly vibration testing.

As a result, as of November 2018, the project had used about 4.5 weeks of schedule reserves to cover delays associated with these activities. The use of reserves beyond what the project had planned for the repairs pushed the restart of spacecraft element integration and test activities out about a week to November 14, 2018. Figure 6 compares the project's initial membrane cover assembly schedule in June 2018 to the actual schedule in November 2018.

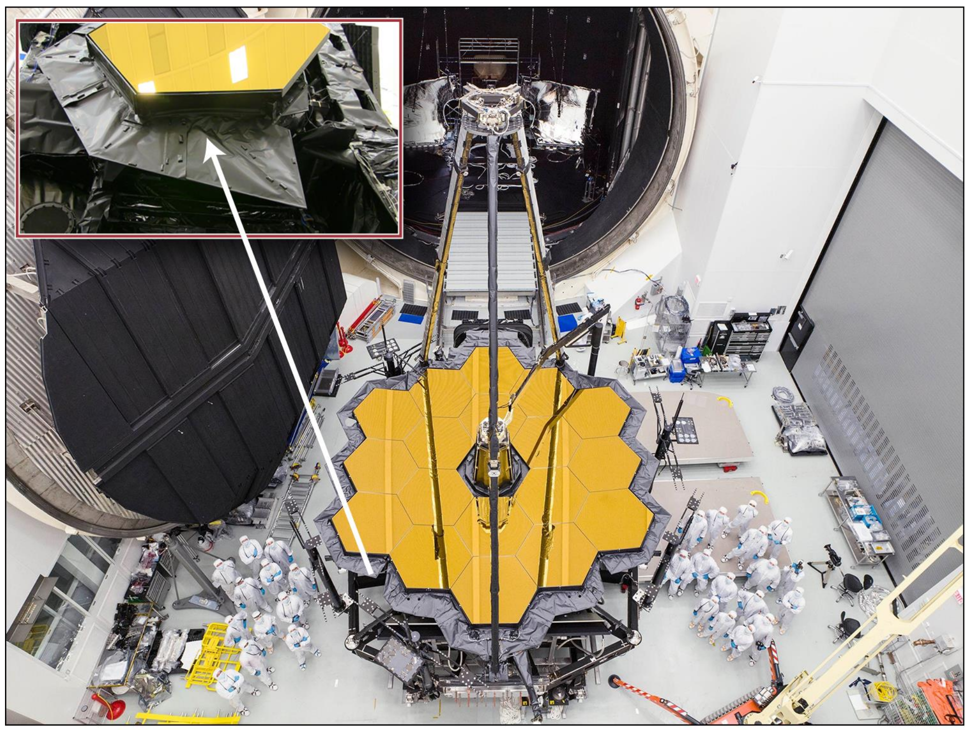
Figure 6: James Webb Space Telescope Membrane Cover Assembly (MCA) Repairs Schedule and Use of Schedule Reserves



Source: GAO analysis of National Aeronautics and Space Administration and Northrop Grumman data. | GAO-19-189

While the project repaired the membrane cover assembly, it also used this time to conduct risk mitigation activities on OTIS. For example, the project worked to mitigate a design issue on the frill connections. The frill is composed of a single layer of blankets placed around the outside of the primary mirror used to block stray light (see figure 7).

Figure 7: James Webb Space Telescope Primary Mirror and Frill



The frill is the black skirt surrounding the primary mirror that is used to block stray light.

Source: Northrop Grumman Aerospace Systems. | GAO-19-189

A combination of modeling and inspections revealed that most of the frill sections did not have as much slack as expected at the near-absolute zero cryogenic temperatures of space. This caused shrinkage that put stress on the edges of the outer ring of mirrors, which could affect the stability of the optical mirror and image quality. The project loosened these outer connections by adding a ring to the connecting points. As of November 2018, project officials said they were in the process of verifying the fix through inspections.

Examples of technical issues and risks that the project continues to face during the remaining phases of integration and test include:

- The project is working to mitigate a design issue on the sunshield membrane tensioning system—which helps deploy the sunshield and maintain its correct shape. In our February 2018 report, we found that Northrop Grumman was planning to modify the design of the membrane tensioning system after one of the sunshield's six membrane tensioning systems experienced a snag when conducting folding and deployment exercises on the sunshield in October 2017.[22] The project and Northrop Grumman determined that a design modification was necessary to fully mitigate the issue, which includes modifying clips used to progressively release the cable tension and adding guards to control the excess cable.
- The project identified a concern that the depressurization of trapped air in the folded sunshield membrane when the fairing separates to release the JWST observatory may overly stress the membrane material. The project is working with Arianespace—the company responsible for operating JWST's launch vehicle—and experts at the Kennedy Space Center to resolve this concern. Officials estimated that a design solution would be in place in mid-2019. However, if the project determines that it needs to reinforce the membrane covers to survive excessive residual pressure as it works on this design solution, a multi-month schedule delay could occur.
- As of November 2018, the project has mitigated 21 of its 47 hardware and software risks to acceptable levels, and reviews these risks monthly for any changes that might affect the continued acceptability of the risk.[23] Five of these 21 risks are related to the project's more than 300 potential single point failures—several of which are related to the deployment of the sunshield.[24] The project is actively working to mitigate the remaining 26 risks to acceptable levels or closure prior to launching.

The project also has several first-time and challenging integration and test activities remaining. For example, the project must integrate OTIS and the

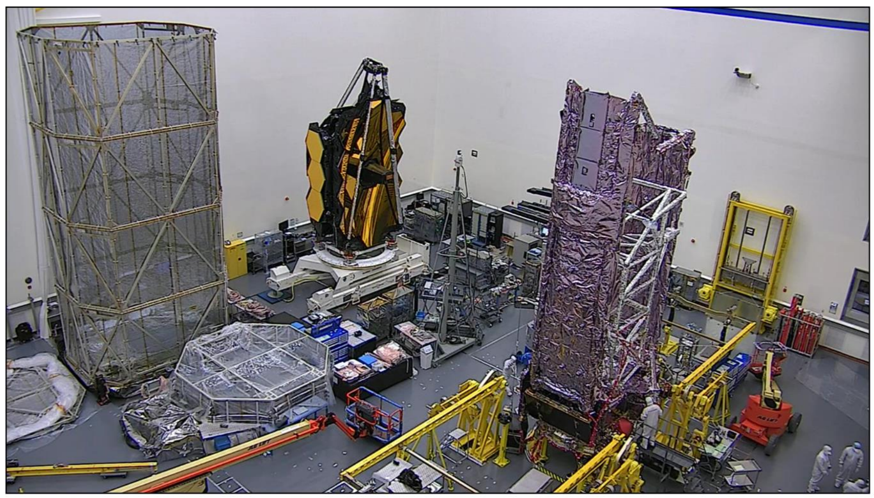
[22]GAO-18-273.

[23]NASA risk guidance states that when a risk is accepted, it is typically because the performance risks associated with the performance requirements are all within tolerable levels. NASA Procedural Requirements 8000.4B *Agency Risk Management Procedural Requirements* (Dec. 6, 2017) and NASA Special Publication 2011-3422 *NASA Risk Management Handbook* (Nov. 2011).

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

completed spacecraft element and test the full observatory in the final integration phase, which includes another set of challenging environmental tests. See figure 8 for an image of OTIS and the spacecraft element prior to being integrated.

Figure 8: Optical Telescope Element and Integrated Science Instrument Module (OTIS) and Spacecraft Element Together in Northrop Grumman Clean Room



Source: Northrop Grumman Aerospace Systems. | GAO-19-189

As previously discussed, the project also has two remaining deployments of the sunshield, and prior deployments have taken longer than planned. To help mitigate the risks associated with the deployments, the project added additional time for deployments in the 2018 replanned schedule based on lessons learned from prior deployments. The two remaining deployments are to occur after spacecraft element integration and test and again after observatory integration and test.

The JWST project office is required to evaluate whether the project can complete development within its revised cost and schedule commitments at its next major review—the system integration review—planned for August 2019. This review is to occur after the project has completed two major tasks—OTIS and spacecraft element integration and test. The review is to evaluate whether the project (1) is ready to enter observatory integration and test, and (2) can complete remaining project development with acceptable risk and within its cost and schedule constraints. NASA guidance does not require projects to conduct a JCL at this review. However, project officials said that they plan to conduct another schedule risk analysis in the future. They do not intend to complete a new JCL for the same reasons they did not complete one for the 2018 replan—because costs are almost entirely related to the workforce and can be derived from a schedule that takes into account known risk.

While not required, conducting a JCL prior to the system integration review would inform NASA about the probability of meeting both its cost and schedule commitments. If the project proceeds with its plan to conduct only a schedule risk analysis, NASA would be provided only with an updated probability of meeting its schedule commitments. Our cost estimating best practices recommend that cost estimates should be updated to reflect changes to a program or kept current as it moves through milestones and as new risks emerge.[25] In addition, government and industry cost and schedule experts we spoke with noted that integration and testing is a critical time for a project when problems can develop. These experts told us that completing a JCL is a best practice for analyzing major risks at the most uncertain part of project execution. Conducting a JCL at system integration review—a review that occurs during the riskiest phase of development, the integration and test phase—would allow the project to update its assumptions of risk and uncertainty based on its experiences in OTIS and spacecraft element integration and test. The project could then determine how those updated assumptions affect overall cost and schedule for the JWST project.

As noted above, the project has many risks to mitigate, technical challenges to overcome, and challenging test events to complete, which could affect the project's schedule and risk posture. Further, the project has an established history of significant cost growth and schedule delays. In its June 2018 letter notifying an appropriate congressional committee of its updated cost and schedule commitments, NASA acknowledged that recent cost growth for the project will likely impact other science missions. Conducting a JCL at system integration review would provide NASA and Congress with critical information for making informed resource decisions on the JWST project and its affordability within NASA's portfolio of projects more broadly.

[25] GAO-09-3SP.

NASA Is Augmenting Oversight of Contractor and Project Performance, and Identified the JWST Project Manager as Responsible for Sustaining Changes

NASA has taken steps to augment oversight of the contractor and project following the discovery of the embedded design flaws and workmanship errors that contributed to the project's most recent schedule delays and cost increases. See table 1 for examples of changes NASA has made to contractor and project oversight—some of which NASA self-identified and others that were in response to IRB recommendations. The IRB made 31 recommendations that ranged from improving employee morale to improving security during transporting JWST to its launch site.

Table 1: Examples of Changes to Oversight of Contractor and Project Performance after James Webb Space Telescope Schedule Delays in 2018

Category	Prior to April 2018	Starting in April 2018 or later
Contractor	NASA on-site coverage consisted of permanent technical support staff, rotating management staff with 6-day rotation periods, and activity-based engineering coverage.	NASA on-site coverage consists of permanent technical support, one to two senior management staff on-site at all times, and regular lead engineer coverage.
Contractor	NASA management relied on Northrop Grumman notices to attend select table top meetings, which are meetings that review integration and test procedures before activities take place.	NASA management attends all table top meetings. Project officials said that the increased attendance allows them to weigh in early on possible procedural issues and government mandatory inspection points.
Contractor	Defense Contract Management Agency provided part-time oversight of software and quality assurance processes at the Northrop Grumman facility. Oversight personnel were on site for primarily one shift per day.	Defense Contract Management Agency provides full-time oversight of software and quality assurance processes at the Northrop Grumman facility. Oversight personnel are on-site two shifts a day, 7 days a week.
Project	Four working groups were involved in areas of commissioning; the Deployment Working Group planned and oversaw observatory deployment.	NASA implemented an Independent Review Board (IRB) recommendation by selecting a Commissioning Manager to oversee observatory deployment as well as coordinate relevant working groups.
Project	NASA, Northrop Grumman, and Defense Contract Management Agency identified major design or other technical issues through integration and test events.	NASA implemented an IRB recommendation in conjunction with Northrop Grumman to conduct comprehensive audits of designs, processes, and tests to identify areas that may be susceptible to future design problems or workmanship errors.
Project	The IRB found that communication channels with the contractor, the public, and within NASA were uncoordinated and contained conflicting information on the project's status.	NASA implemented an IRB recommendation by combining center-level and headquarters review meetings to improve consistency of communication of project status.

Source: GAO analysis of National Aeronautics and Space Administration (NASA) and Defense Contract Management Agency documents and interviews with officials. | GAO-19-189

NASA has also used award fees to try to incentivize Northrop Grumman to improve its performance. In a July 2018 hearing on the JWST program before the House Science, Space, and Technology Committee, Administrator Bridenstine stated that NASA had reduced the available award fee through commissioning by $28 million out of a total of about $60 million. Northrop Grumman also did not earn its full award fee in the two most recent periods of performance that NASA assessed.

- For the performance period of April 1, 2017 to September 30, 2017, Northrop Grumman earned approximately 56 percent of the available award fee. Reasons that NASA cited for its evaluation of award fees in this period included workmanship errors on the propulsion system, schedule delays, as well as issues with schedule execution, management, and quality control.
- For the period of October 1, 2017 to March 31, 2018, Northrop Grumman earned none of the available award fee. Northrop Grumman's overall score was driven by an "unacceptable" rating in schedule and cost due to delays and in anticipation of exceeding the project's $8 billion cost cap. Northrop Grumman received an "excellent" rating under the technical category, but the evaluation noted ongoing issues with quality controls, which resulted in delays. For example, the process steps for applying voltage to the spacecraft's pressure transducers were not clear enough, which resulted in technician error and irreparable damage to the hardware.

According to Northrop Grumman officials, the contractor has started to take action to try to improve its quality assurance processes. Officials described actions that ranged from rewriting hardware integration and test procedures to starting efforts to change aspects of the company's culture that contributed to quality control issues. For example, in July 2018, Northrop Grumman initiated a JWST mission assurance culture change campaign to increase focus on product quality and process compliance. This effort includes having inspectors affirm by signature that they have personally inspected, verified, and confirmed that all aspects of an activity meet quality standards. According to the form instructions, if the inspector is uncertain on compliance or if instructions are unclear, workers are to halt work, investigate and assess the situation, and request help to resolve the situation. Project and Northrop Grumman officials provided an example of these changes working. During a manual deployment of a radiator panel, a Northrop Grumman employee discovered that a flap used as thermal protection for a radiator was installed incorrectly and reported the error. Northrop Grumman technicians found that this flap had been swapped with another flap in the process of moving them to be installed and corrected the problem before work proceeded.

Further, NASA and Northrop Grumman are conducting audits to try to minimize the risk of failures during the remaining phases of integration and test. These audits are conducted on items that have not been fully tested, are in workmanship-sensitive areas, or have had a late design change. The first phase of the audit was completed in September 2018 and found no major design issues or hardware rework required. The project plans to audit other areas through at least spring 2019, but will add audits if needed.

The JWST oversight structure includes a number of positions that could be responsible for ensuring that the recent augmentations to contractor and project oversight are sustained through launch (see table 2).

Table 2: Positions Responsible for Aspects of James Webb Space Telescope (JWST) Oversight and Performance

Position	Roles and Responsibilities
Associate Administrator	The Associate Administrator is responsible for integrating the technical and programmatic elements of NASA. As such, the Associate Administrator oversees the NASA centers, programs, and technical authorities. The Associate Administrator oversees the planning, directing, organization, and control of the day-to-day agency technical and programmatic operations.
Science Mission Directorate Associate Administrator	The Science Mission Directorate Associate Administrator is responsible for implementing and managing the directorate's program portfolios. This includes defining, funding, evaluating, and overseeing implementation of respective programs and projects, and ensuring outcomes meet schedule and cost constraints. He or she is accountable for cost, schedule, and technical performance, mission safety, and program and project success.
JWST Program Director	The JWST Program Director reports to the Associate Administrator for the Science Mission Directorate and is responsible for implementing the program. The JWST Program Director also reports the program's status to the NASA Associate Administrator on a weekly basis and directly interfaces with the JWST Program Manager and with the project office in the implementation of JWST.
Goddard Space Flight Center Director	The Goddard Space Flight Center Director is responsible and accountable for all activities assigned to the center. He or she is responsible for the institutional activities and for ensuring the proper planning for and assuring the proper execution of programs and projects assigned to the center.
JWST Program Manager	The JWST Program Manager is responsible for the formulation and implementation of the program as described in NASA policy. This includes responsibility and accountability for ensuring program safety; technical integrity; technical, cost, and schedule performance; and mission success. In addition, the program manager has responsibility for developing and presenting time-phased cost estimates, budget, and funding requirements, among other things.

Position	Roles and Responsibilities
JWST Project Manager	The JWST Project Manager has overall responsibility for managing the project team and ensuring that the project delivers a technically correct system within cost and schedule. The project manager is responsible for the formulation and implementation of the project as described by NASA policy. This includes responsibility and accountability for the project safety, technical integrity, and mission success of the project, while also meeting programmatic (technical, cost, and schedule performance) commitments.

Source: GAO analysis of National Aeronautics and Space Administration (NASA) policies and guidance. | GAO-19-189

In response to our review, NASA officials clarified that the project manager has sole responsibility for ensuring that these improvements are sustained through launch. Further, these officials stated that the project office is responsible for monitoring these changes at the project level and at Northrop Grumman. The project manager's continued focus on these efforts will be important because:

- The project is implementing a wide span of improvement efforts, ranging from more on-site coverage at the contractor facility to cultural improvements, which will now need to be sustained for an additional 29 months.
- The project has had recurring issues with effective internal and external communication as well as defining key management and oversight responsibilities, both of which are important to sustaining oversight. For example, the Independent Comprehensive Review Panel identified communication problems—between the JWST project and Science Mission Directorate management as well as between NASA and Northrop Grumman—and that the project's governance structure lacked clear lines of authority and accountability. In December 2012, we found the JWST project had taken several steps to improve communication—such as instituting meetings that include various levels of NASA, contractor, and subcontractor management—but the IRB's findings in 2018 indicate that communication and governance issues have resurfaced in some areas.[26] For example, the IRB found that communication with key stakeholders including the science community, Congress, and NASA leadership, has been variable and at times inconsistent.
- The project may encounter new schedule pressures as it proceeds through integration and test. A senior NASA official with expertise in workmanship issues told us that schedule pressure is a key reason for increased quality problems on projects. For example, this official said

[26]GAO-13-4.

that companies tend to give experts leniency to operate without the burden of quality assurance paperwork when schedule pressures arise, which can lead to workmanship errors. While JWST project officials told us they do not view this as applicable to their project, the perspective regarding potential schedule pressures and workmanship is important to keep focus on given the magnitude of technical challenges and delays the project has faced.

We will continue to monitor the project's efforts at maintaining these oversight augmentations in future reviews, given that less than a year has passed since the project began implementing many of them. Moreover, the project may find that some actions will be required of officials outside the project, particularly since the communication problems identified by the IRB may well extend to headquarters' interaction with stakeholders from the science community, industry, and the Congress.

Conclusions

JWST is one of NASA's most expensive and complex science projects, and NASA has invested considerable time and resources on it. The project first established its cost and schedule baseline in 2009. Since then, the project made progress by completing two of five phases of integration and test, but has also experienced significant cost growth and schedule delays. However, the project did not complete a JCL analysis as part of its second replan. Between now and its system integration review planned for August 2019, the JWST program will have to continue to address technical challenges and mitigate risks. Conducting a JCL would better inform decision makers on the status of the project as they determine whether the project can complete remaining project development with acceptable risk and within its cost and schedule constraints. Given the project is now on its third iteration of cost and schedule commitments, conducting a JCL is a small step that NASA can take to demonstrate it is on track to meet these new commitments.

Recommendation for Executive Action

We are making the following recommendation to NASA:

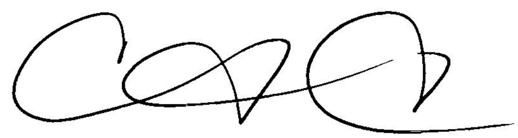
The NASA Administrator should direct the JWST project office to conduct a JCL prior to its system integration review. (Recommendation 1)

Agency Comments and our Evaluation

We provided a draft of this report to NASA for comment. In written comments, NASA agreed with our recommendation. NASA expects to complete the JCL by September 2019, prior to the system integration review. The comments are reprinted in appendix II. NASA also provided technical comments, which have been addressed in the report, as appropriate.

We are sending copies of this report to the appropriate congressional committees, the NASA Administrator, and other interested parties. In addition, the report is available at no charge on the GAO website at 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 III.



Cristina T. Chaplain
Director
Contracting and National Security Acquisitions

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The Honorable Eddie Bernice Johnson
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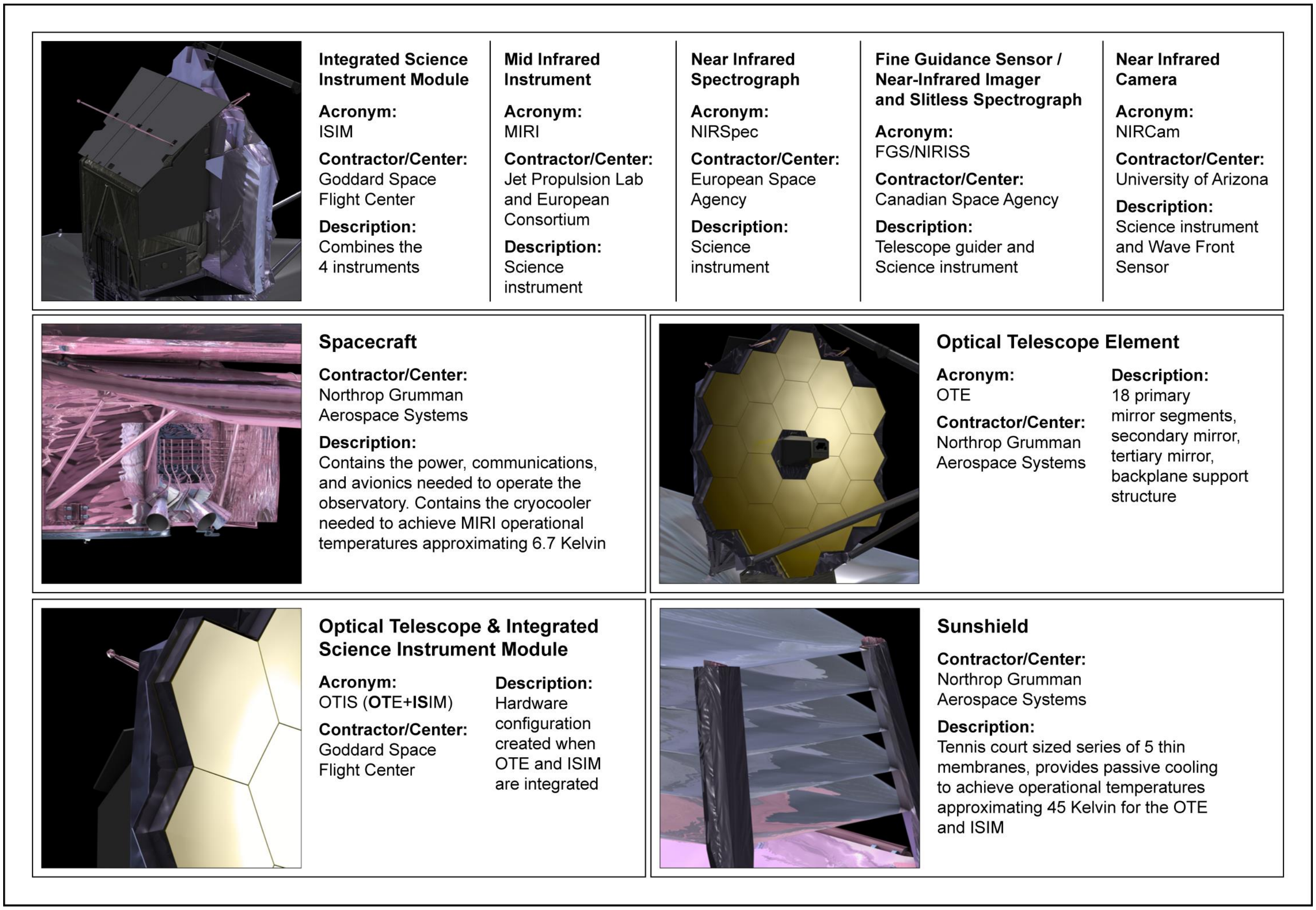
The Honorable Frank D. Lucas
Ranking Member
Committee on Science, Space and Technology
House of Representatives

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

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



Sources: GAO (analysis); National Aeronautics and Space Administration (data and images). | GAO-19-189

Appendix II: Comments from the National Aeronautics and Space Administration

National Aeronautics and Space Administration

Headquarters
Washington, DC 20546-0001

Reply to Attn of: Science Mission Directorate

FEB 1 2019

Ms. Cristina T. Chaplain
Director
Contracting and National Security Acquisitions
United States Government Accountability Office
Washington, DC 20548

Dear Ms. Chaplain:

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to review and comment on the Government Accountability Office (GAO) draft report entitled, "James Webb Space Telescope: Opportunity Nears to Provide Additional Assurance That Project Can Meet New Cost and Schedule Commitments" (GAO-19-189) dated November 30, 2018.

In the draft report, GAO makes one recommendation intended to improve cost and schedule estimates relating to the James Webb Space Telescope (JWST) project. Specifically, GAO recommends the following:

> **Recommendation 1:** The NASA Administrator should direct the JWST project office to conduct a Joint Confidence Level (JCL) prior to its system integration review.
>
> **Management's Response:** NASA concurs with the recommendation to perform a JCL. The JCL will be completed prior to the System Integration Review targeted for late summer, 2019.
>
> **Estimated Completion Date:** September 30, 2019.

Once again, thank you for the opportunity to comment on the subject draft report. If you have any questions or require additional information, please contact Peter Meister on (202) 358-1557.

Sincerely,

Dr. Thomas H. Zurbuchen
Associate Administrator
for Science Mission Directorate

Appendix III: 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, Molly Traci (Assistant Director), Karen Richey (Assistant Director), Jay Tallon (Assistant Director), Brian Bothwell, Daniel Emirkhanian, Laura Greifner, Erin Kennedy, Jose Ramos, Sylvia Schatz, Roxanna Sun, and Alyssa Weir made key contributions to this report.

Appendix IV: Accessible Data

Data Tables

Accessible Data for Figure 5: Estimated Workforce Required to Finish Assembling and Operating James Webb Space Telescope

Fiscal year	Northrop Grumman	Space Telescope Science Institute	Civil Servants	Project Support Contractors	Other
2018	450.5	305	92	170	68.3
2019	412.6	315	92	170	16
2020	368.7	315	92	170	7
2021	81.4	315	45	130	1.2
2022	8.3	315	16.5	18	0
2023	5	315	16.5	16	0
2023	5	315	16.5	13	0
2025	5	315	16.5	12	0
2026	3.3	289	12	7	0

Agency Comment Letter

Accessible Text for Appendix II Comments from the National Aeronautics and Space Administration

FEB 1 2019

Ms. Cristina T. Chaplain

Director

Contracting and National Security Acquisitions

United States Government Accountability Office

Washington, DC 20548

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Recommendation 1: The NASA Administrator should direct the JWST project office to conduct a Joint Confidence Level (JCL) prior to its system integration review.

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Estimated Completion Date: September 30, 2019.

Once again, thank you for the opportunity to comment on the subject draft report. If you have any questions or require additional information, please contact Peter Meister on (202) 358-1557.

Dr. Thomas H. Zurbuchen Associate Administrator for Science Mission Directorate

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