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Report to Congressional Committees

May 2021

JAMES WEBB SPACE TELESCOPE

Project Nearing Completion, but Work to Resolve Challenges Continues

A Century of Non-Partisan Fact-Based Work

GAO-21-406

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Highlights

Highlights of GAO-21-406, a report to congressional committees

May 2021

JAMES WEBB SPACE TELESCOPE

Project Nearing Completion, but Work to Resolve Challenges Continues

Why GAO Did This Study

JWST, a large, deployable telescope, is one of NASA's most complex projects and top priorities. It is the scientific successor to the Hubble Space Telescope and is intended to help scientists better understand how galaxies and the universe have evolved and study planets in other solar systems. Problems discovered during integration and testing caused multiple delays that led NASA to replan the project in June 2018. Now estimated to cost $9.7 billion, the project's costs have nearly doubled and its launch date has been delayed by over 7 years since its cost and schedule baseline was established in 2009.

Conference Report No. 112-284 included a provision for GAO to assess the project annually and report on its progress. This, GAO's ninth related report, assesses (1) the extent to which technical issues and other challenges affected progress against cost and schedule commitments since 2019 and (2) how the JWST project managed known risks to completing its mission. To conduct this work, GAO reviewed relevant NASA policies, analyzed NASA and contractor data, and interviewed NASA and contractor officials.

What GAO Recommends

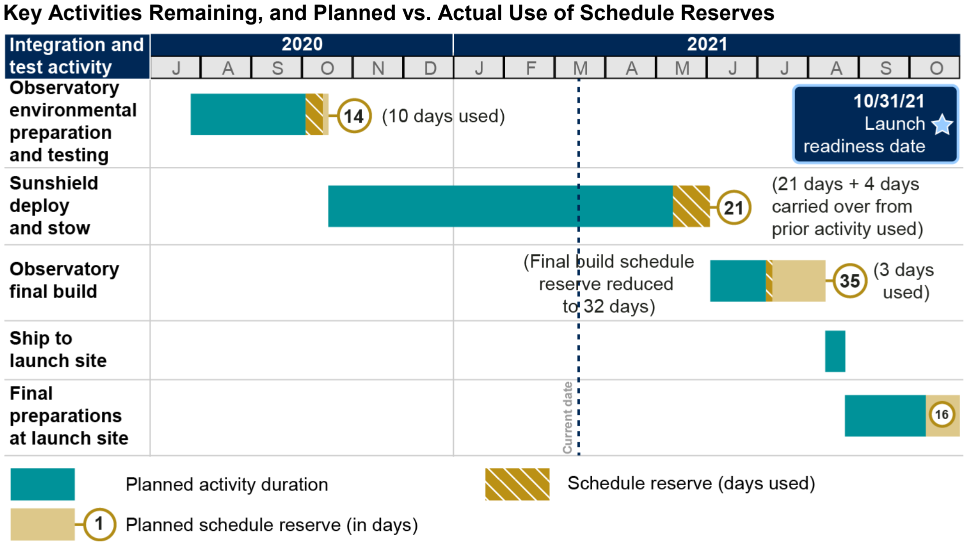
GAO is not making any new recommendations. Over eight previous reports, GAO has made several recommendations to NASA on the management of this project. NASA completed efforts to address those that remained relevant in 2019. We provided NASA with a draft of this report for review. The agency told us it had no comments.

View GAO-21-406. For more information, contact W. William Russell at (202) 512-4841 or russellw@gao.gov.

What GAO Found

Since 2019, the National Aeronautics and Space Administration's (NASA) James Webb Space Telescope (JWST) project, one of the agency's most complex science missions, has made considerable progress toward launch—now planned for October 2021—by resolving technical issues, but some schedule and cost challenges remain. For example, in March 2021, NASA officials reported that launch vehicle anomalies that the project's international partners need to resolve will likely lead to a further delay to the launch date. The project has also used schedule reserves—extra time set aside to accommodate unforeseen risks or delays—faster than expected to address issues such as repairing and strengthening the sunshield. As a result, the project has less schedule reserve than planned to complete remaining activities. The project is also completing redesigns for key parts of the observatory, including actuators, which help unfurl the sunshield. Further, the project continues to address technical problems that could affect the project's ability to meet cost commitments if the contractor workforce is needed longer than planned.

Key Activities Remaining, and Planned vs. Actual Use of Schedule Reserves



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-21-406

Including the launch delay risk, the project is managing 39 risks—11 fewer than when GAO reported in January 2020. The project reduced the number of known mission risks, but expects to continue managing risk after launch to complete mission objectives. Of the 39 risks, NASA will continue to manage 26 after launch, including those related to sunshield deployment and the functionality of the observatory's sensitive, near-infrared camera. Some of these risks could result in loss of mission, but NASA assessed that they are unlikely to occur. The JWST project established a commissioning organization in part to mitigate risks. For example, the team developed 207 contingency plans to address a variety of issues that may be faced during observatory launch, commissioning, and operation.

Contents

Abbreviations

COVID-19	Coronavirus Disease 2019
Goddard	Goddard Space Flight Center
JWST	James Webb Space Telescope
NASA	National Aeronautics and Space Administration

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
A Century of Non-Partisan Fact-Based Work
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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. Its innovative technologies and design are meant to help NASA and others understand the origins of the universe and the creation and evolution of the first stars and galaxies, among its other missions. The project has a history of cost overruns, schedule delays, and technical difficulties, driven in part by the enormous complexity of the project and workmanship issues. The program replanned its cost and schedule in June 2018, and extended its launch date again in July 2020.[1] JWST is now estimated to cost approximately $9.7 billion and launch in October 2021, which represents cost growth of 95 percent and 88 months of schedule delays since the project's cost and schedule baselines were first established in 2009. However, the project has entered the final phase of its lengthy and complex integration and testing period and has resolved many technical challenges throughout its development.[2]

In November 2011, Conference Report No. 112-284, which accompanied the Consolidated and Further Continuing Appropriation Act, 2012, included a provision for GAO to assess the 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, and program technical status.[3] This report is our ninth in response to that provision. For this report, we assessed (1) the extent to which technical issues and other challenges affected progress against cost and schedule

[1]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. 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).

[2]Systems integration and test is the process of assembling and functionally testing individual instruments and spacecraft subsystems into a total, operating, self-compatible system.

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

commitments since 2019 and (2) how the JWST project managed known risks to completing its mission.

To assess the extent to which technical issues and other challenges affected progress against cost and schedule commitments since 2019, we examined the status of the project's schedule, cost, and technical risks. Specifically, we analyzed monthly JWST status reports provided to NASA management to monitor schedule reserve levels and usage, identify potential risks and technical challenges that may affect the project's schedule, and gain insights on the project's progress. We also reviewed contractor documentation for further information on the schedule and cost implications of technical challenges identified by the project. We compared the project's revised cost and schedule baseline to the project's current forecasts to determine what changes have been made, including changes to NASA and contractor workforces. We interviewed officials from NASA Headquarters, JWST project officials at Goddard Space Flight Center (Goddard), NASA Independent Verification and Validation officials, and contractors concerning project progress and remaining technology, cost, and schedule risks.

To assess the extent to which the JWST project managed known risks to completing its mission, we reviewed NASA risk management policy and guidance to understand how projects consider risk. We examined and analyzed monthly risk registers and summary reports to determine the number and severity of risks the project has managed through design and test activities. We reviewed statements within the reports to identify risks that will continue through launch and commissioning of the observatory and asked project officials to verify these findings.[4] We interviewed project officials and reviewed related documentation to determine the extent to which NASA has developed contingency plans for these remaining risks and other anomalous occurrences during launch and commissioning.

We conducted this performance audit from May 2020 to May 2021 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

[4]Commissioning consists of activities completed after launch to prepare the observatory for science operations. For JWST, commissioning includes establishing communications, placing the observatory on orbit, deploying multiple observatory elements, and calibrating science instruments.

the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

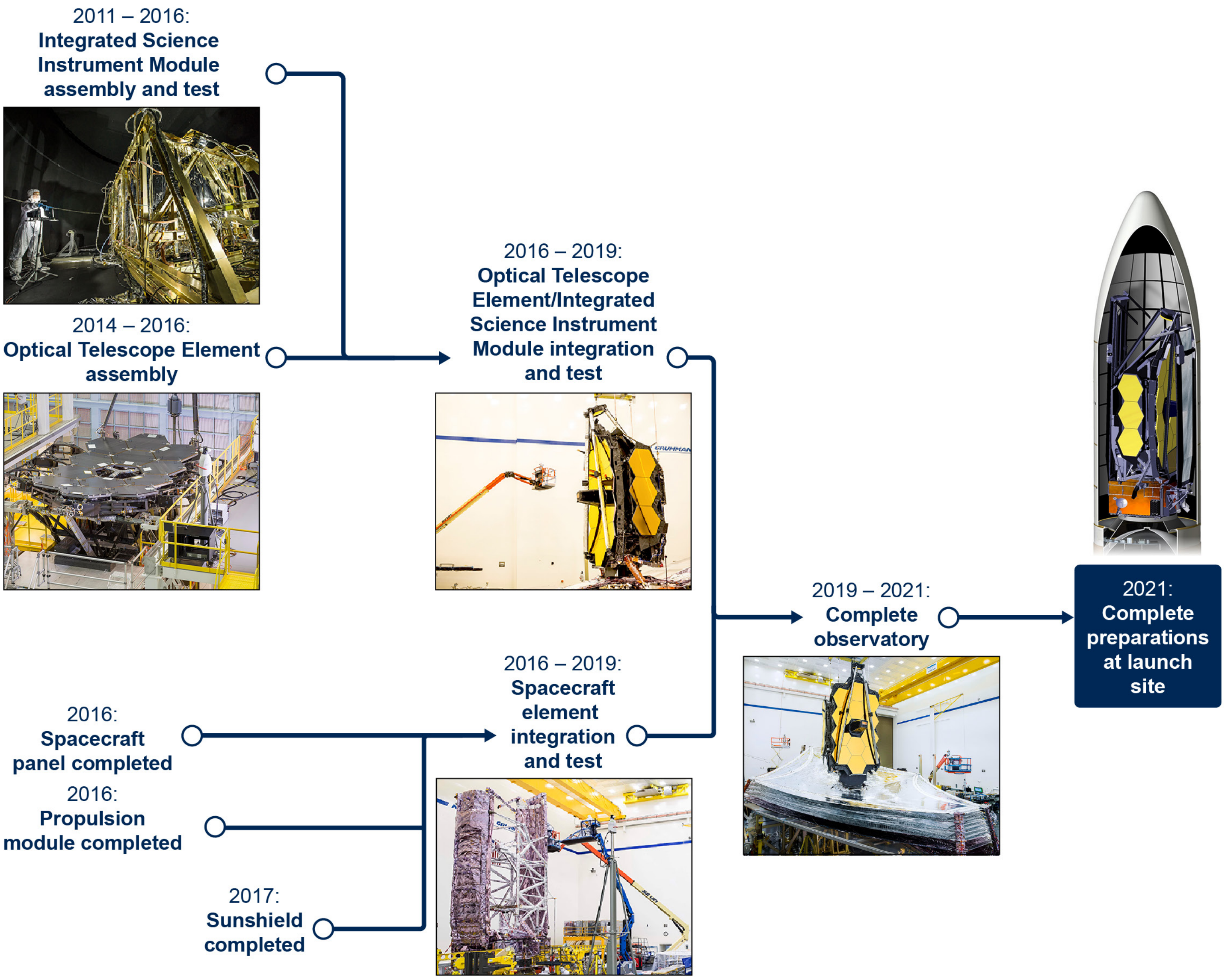
When complete, JWST will be a large, deployable space telescope, optimized for infrared observations. It is the scientific successor to the aging Hubble Space Telescope launched 29 years ago. JWST is designed for a 5-year mission to find the first stars, study planets in other solar systems, search for 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 Earth. With a 6.5-meter (21.3 foot) diameter mirror, JWST is expected to operate at about 100 times the sensitivity of the Hubble Space Telescope. Its science instruments are designed to observe faint infrared sources and therefore are required to operate at extremely cold temperatures. To help keep these instruments cold, the JWST project will rely on a multi-layered, tennis court-sized sunshield to protect the mirrors and instruments from the sun's heat.

When complete, the observatory segment will include several elements (Optical Telescope Element, Integrated Science Instrument Module, and spacecraft) and major subsystems (sunshield and cryocooler.) The project is uniquely complex due to this design, which includes several components that are the first of their kind, including the sunshield and cryocooler. Additionally, JWST uses 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 and appendix I for more details, including a description of the elements, major subsystems, and instruments.

JWST depends on more deployment events—steps after launch that configure the observatory for its mission and place it in orbit—than a typical science mission. After launch, JWST will go through a multi-step deployment and commissioning process that takes approximately 6 months to complete. Typically, satellite operations are tested before launch in simulated space environments to the extent possible. However, due to the JWST observatory's large size, it is nearly impossible to perform deployment tests of the fully assembled observatory in a thermal vacuum chamber to simulate the space environment. Therefore, the verification of deployment elements is accomplished by a combination of lower level component tests in flight-simulated environments; ambient deployment tests for subsystem, element, and observatory levels; and detailed analysis and simulations at various levels of assembly. Due to the project's scope and complexity, the integration and test phase is divided into five separate efforts, which to date have required about 10 years to complete.[5] Figure 1 shows the multiple layers of integration and testing for major components of the JWST observatory.

[5]NASA classifies JWST as a single-project program—those that tend to have long development and operational lifetimes and represent a large investment. The JWST program office is based at NASA headquarters and oversees the project office based at Goddard Space Flight Center responsible for execution of the JWST development, integration, and testing. NASA NPR 7120.5E, *NASA Space Flight Program and Project Management Requirements w/ Changes 1-18*, Expiration date Dec. 14, 2021, Appendix A, Definitions.

Figure 1: James Webb Space Telescope Component and Observatory Test and Integration Activities



Source: GAO analysis of National Aeronautics and Space Administration (NASA) data, photos used with the permission of NASA and are publicly available. | GAO-21-406

For the majority of work remaining, the JWST project is relying on two contractors: Northrop Grumman in Redondo Beach, California and the Association of Universities for Research in Astronomy's Space Telescope Science Institute in Baltimore, Maryland. 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 the Institute 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 launch vehicle, provided by the European Space Agency.

JWST's Risk Management Approach

NASA has embedded risk management into its space flight project and program management policy. It is among the several items that projects should consider during formulation and reevaluate throughout the life cycle, including at key milestone reviews. Specifically, NASA uses risk-informed decision-making processes as well as continuous risk management oversight to identify and manage project risk.[6] Each project develops a risk management plan that, among other things, defines its approach to continuous risk management, how likelihood and consequence severity associated with risks will be measured, and risk communication protocols between levels of management. Stakeholders—frequently engineers with subject matter expertise—-may elevate issues that they perceive as risks to the achievement of project performance requirements. These risks are discussed in terms of unwanted scenarios, their likelihood, and the potential negative consequences to performance requirements should they occur. Projects may assign an overall risk level based on the likelihood and consequence of the unwanted scenario that is raised, where, for example, risks with high impact and high likelihood would be assessed as higher overall risk to the project than scenarios of equal likelihood but lesser negative consequence.

Risks managed by NASA projects fall into four domains: cost, schedule, technical, and safety risks. Projects may apply five different management approaches to the risks they identify; they may accept, mitigate, watch,

[6]Risk-informed decision-making is used to establish baseline performance requirements through the application of performance measures, which includes model-based risk metrics, along with other considerations within a deliberative process. Continuous risk management is a systematic and iterative process that identifies, analyzes, plans, tracks, controls, communicates, and documents risks associated with implementation of designs, plans, and processes included in the baseline. NASA NPR 8000.4B, Agency Risk Management Procedural Requirements, Dec. 06, 2017.

research, or elevate each risk.[7] The approach a project uses may change over time as more information is gathered or analysis is completed. A project may accept residual risk remaining after the completion of any mitigating steps but this decision must be acknowledged, reviewed, and agreed to by technical authorities within NASA management. The project may close a risk if risk management activities are determined to have resolved it.

The JWST project captures and communicates its current risk standing via monthly-updated risk registers. Each register lists the risks that remain open, states which of the management approaches are being applied, and provides a description of the likelihood, potential severity, and resulting overall risk for each. Further, the project groups the risks according to the observatory element or capability that would be affected by the related unwanted event and includes a description of mitigating steps as applicable. The JWST project uses this information to inform content in monthly project status updates to NASA center and directorate management. This information is also used to assess the aggregate risk presented by linked individual risks.

History of Schedule Delays and Cost Growth

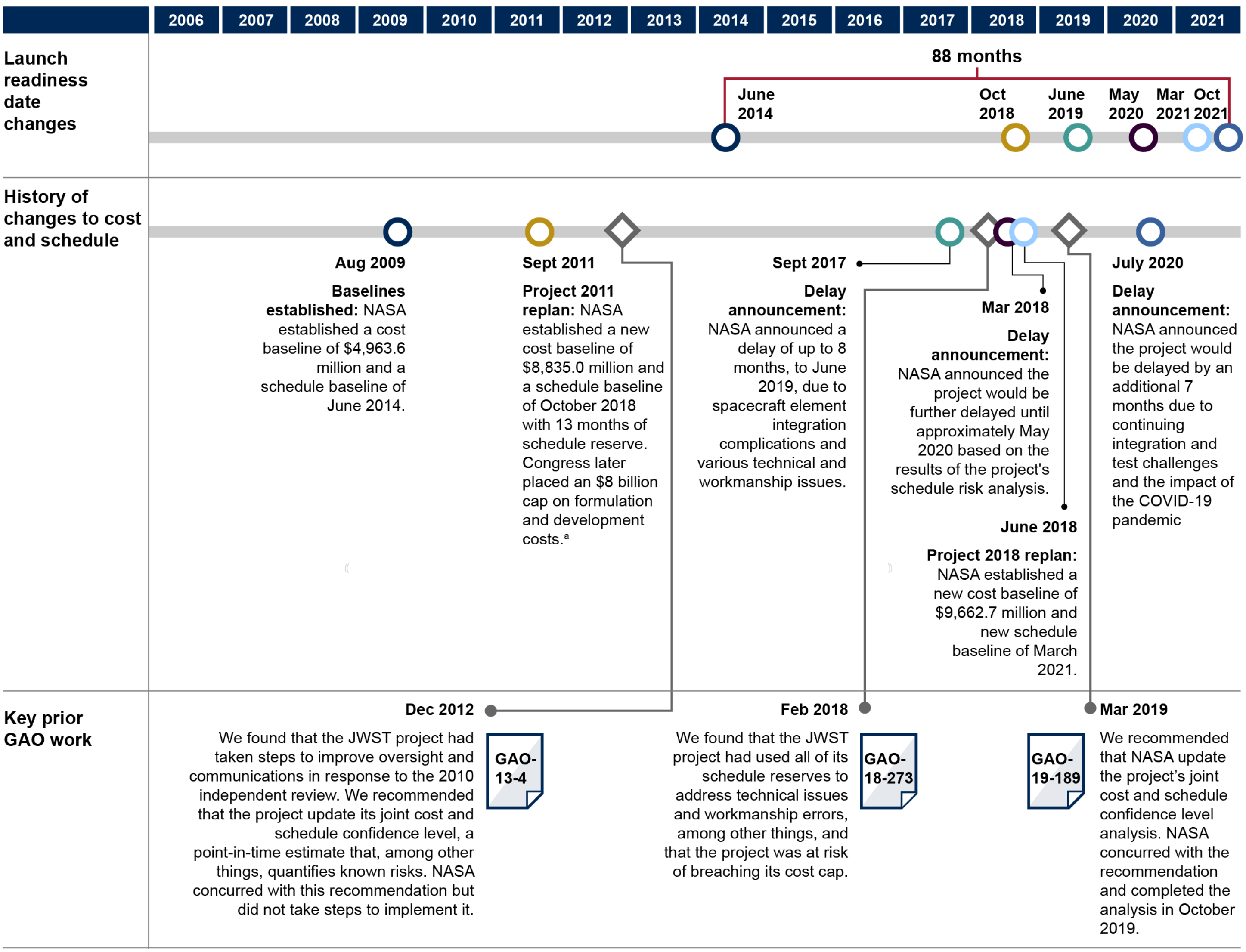
The JWST program has a history of significant schedule delays and project cost increases, which resulted in both the 2011 and 2018 replans. Since the project's schedule and costs were baselined in 2009, the launch date has been delayed by over 7 years and costs have increased by 95 percent. Due to early technical and management challenges, contractor performance issues, and low levels of cost reserve, the JWST program experienced schedule overruns, launch delays, and cost growth. The program underwent a replan in September 2011 and then a rebaseline; further, a statutory $8 billion cap was placed on the

[7]Risks are elevated to the next highest organization unit when no combination of mitigating, research, or monitoring actions will return risk to a tolerable level for a particular scenario.

formulation and development costs for the project.[8] However, in June 2018, after a series of launch delays due to technical and workmanship issues identified during spacecraft element integration, NASA notified Congress that it had revised the JWST program's schedule and cost estimates again. NASA estimated that it would now require 29 more months beyond the estimates agreed to in the 2011 rebaseline and $828 million in additional resources during the program's life cycle to complete JWST. In July 2020, NASA revised its launch readiness date to October 2021, an additional 7-month delay from its prior estimate. (See fig. 2.)

[8]Consolidated and Further Continuing Appropriations Act, 2012, Pub. L. No. 112-55, §622 (Nov. 2011). A replan is a process by which a program updates or modifies its plans. It generally is 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. Rebaselining is the process that results in a change to the project's Agency Baseline Commitment. A rebaseline is initiated if the estimated development cost exceeds the baseline development cost estimate by 30 percent or more or if the NASA Associate Administrator determines other events make a rebaseline appropriate. NASA NPR 7120.5E, NASA Space Flight Program and Project Management Requirements w/ Changes 1-18, Expiration date Dec. 14, 2021, Section 2.4.1.7.

Figure 2: History of Changes to the James Webb Space Telescope (JWST) 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-21-406

[a]Congress requires that NASA treat any cost increase above the cap as if it meets the 30 percent threshold described in 51 U.S.C. § 30104(f). The process associated with this is known as a rebaseline.

In March 2019, we found that NASA had considered many of the program's risks while developing its 2018 replan schedule and cost baseline but recommended that additional analysis be completed to provide NASA and Congress with better insight into project resourcing and affordability.[9] Specifically, a Joint Cost and Schedule Confidence Level is an integrated analysis of a project's cost, schedule, risk, and uncertainty, the result of which indicates a project's likelihood of meeting cost and schedule targets.[10] The project did not complete such an analysis as part of its second replan. Though not required by NASA policy, we recommended that one be conducted given the long history of program challenges and the significant and complex integration events that still needed to be completed.[11] NASA agreed with our recommendation and completed this analysis in October 2019. The analysis determined that there was only a 12 percent confidence level in achieving the planned launch date of March 2021. We reported in January 2020 that technical challenges had placed a strain on the project's schedule, which accounted for the low confidence level.[12] As discussed later in this report, these and a variety of more recent challenges resulted in a further delay to the launch date.

NASA's telescope and other science projects will always have inherent technical, design, and integration risks because they are complex, specialized, and often push the state of the art in space technology. However, apart from unforeseen challenges identified during integration and testing, some issues that affect cost and schedule could be preventable. We and others have reported on a variety of management issues that may have contributed to cost and schedule challenges for JWST and have made dozens of recommendations to improve performance. Among the challenges we identified were optimistic cost and schedule estimates, reliance on analysis that did not reflect all risks, and inadequate contractor oversight and data collection.[13]

[9]GAO, James *Webb Space Telescope: Opportunity Nears to Provide Additional Assurance That Project Can Meet New Cost and Schedule Commitments*, GAO-19-189 (Washington, D.C.: Mar. 26, 2019).

[10]NASA, *NASA Cost Estimating Handbook Version 4.0* (February 2015).

[11]NASA Procedural Requirement 7120.5E, *NASA Space Flight Program and Project Management Requirements w/ Change 1-16* (Aug. 14, 2012).

[12]GAO-20-224.

[13]Since 2012, GAO has made 12 recommendations to NASA concerning aspects of the JWST project. NASA concurred or partially concurred with all of these recommendations and took the necessary steps to fully implement five including GAO's most recent recommendation to conduct a Joint Cost and Schedule Confidence Level prior to its system integration review. The remaining seven recommendations were closed as unimplemented in part because changes in program circumstances made them no longer necessary.

Project officials acknowledge that some of the challenges experienced since the start of integration and testing may have been avoidable. Recognizing this, NASA's Science Mission Directorate initiated a study of its major acquisitions, to include JWST, in July 2019 to identify ways to improve cost and schedule outcomes. According to JWST officials, the study team has identified high-priority challenges, including the cost and schedule uncertainty associated with unprecedented projects, and has completed analyses to identify specific and actionable recommendations to address them. The Science Mission Directorate is developing an implementation plan for these recommendations, which will be included as appendix in the study team's final report.

Schedule and Cost Reserves for NASA Projects

The JWST project, like other complex development efforts we have reviewed, faces numerous risks and potential technical challenges, which often become apparent during integration and testing. To accommodate unanticipated challenges and manage risk, projects include extra time in their schedules, referred to as schedule reserve, and extra funds in their budgets, 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 affect schedule reserve on other elements or major subsystems whose progress is dependent on prior work being finished.

Cost reserve is additional funding within the project manager's budget that can be used to address and mitigate unanticipated issues for any element or major subsystem. Goddard—the NASA center with responsibility for managing JWST—issued procedures detailing the cost and schedule reserve requirements for formulating and executing spaceflight programs.[14] In recent replans, the JWST project has allocated more reserve than indicated by Goddard policy due to the project's complexity. For example, when NASA constructed its 2018 replan for the JWST project, the new schedule included 9.6 months of schedule reserve, well above the approximately 5 months that the Goddard policy would have indicated. Similarly, the 2020 launch date extension allowed

[14]NASA GPR 7120.7, *Schedule and Budget Margins for Flight Projects* (May 4, 2008-May 4, 2015) remains applicable to the JWST program, see NASA, Goddard Procedural Requirements (GPR) 7120.7B, *Schedule and Budget Margins for Flight Projects* (Feb. 28, 2017), Appendix D at pg. 8.

for 86 days of schedule reserve, above the approximately 63 days that would have been indicated by Goddard policy.

Technical Progress Made but Challenges to Schedule and Cost Remain and Additional Launch Delay Likely

JWST Project Has Made Significant Technical Progress since July 2020 Launch Delay

As previously noted, in 2019, NASA completed its Joint Cost and Schedule Confidence Level analysis for the JWST project, which found a 12 percent confidence level in the previous March 2021 launch date. Following this analysis, in July 2020, the project announced a 7-month launch delay from March 2021 to October 2021. This delay was driven by several factors, including recent technical issues and the impact of the Coronavirus Disease 2019 (COVID-19) pandemic. Prior to extending the date, the project conducted a schedule risk assessment, which included known technical risks as well as known and projected effects of COVID-19 through the end of 2020. The analysis excluded certain unquantifiable risks and some developing issues; however, the project chose the new launch date of October 2021, which reflected additional time above what the analysis indicated to account for unanticipated challenges. Specifically, project officials noted that extra time was included for the final deployment activities for the sunshield and other hardware.

Since revising its launch date, the project has completed a significant technical milestone. Specifically, the project's final set of environmental testing, including acoustics and vibration testing on the fully integrated observatory—comprising the spacecraft, sunshield, and instruments—was successfully completed in October 2020. In December 2020, the project completed the final round of sunshield deployment exercises before stowing and preparing the observatory for shipment to the launch site. According to project officials, only minor anomalies occurred during the deployment. The project has also resolved several long-standing schedule concerns that we reported in 2020.[15] For example, the project completed replacement of the command and telemetry processer and

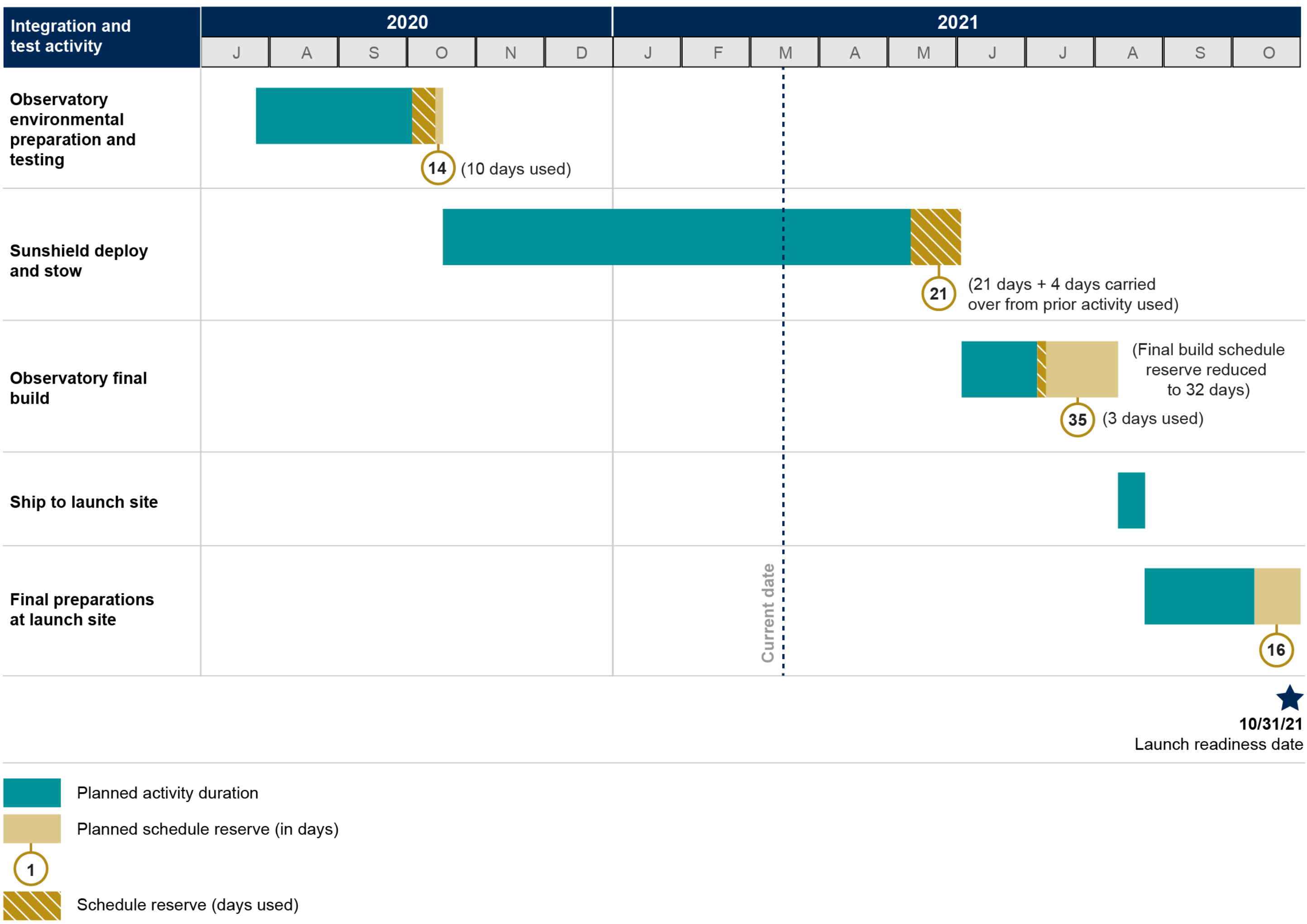
[15] GAO-20-224.

traveling wave tube amplifier hardware. These are key communications components that had consumed approximately 17 weeks of schedule reserve in 2019. Further, the project concluded an audit of 501 voided bolts that were installed on the observatory but were later discovered to not meet specifications. The project conducted strength testing to determine that replacement of these bolts would not be necessary.

Project Has Begun to Use Schedule Reserve Allocated for Later Activities

The project has consumed more schedule reserve than it had allocated for current integration and test activities. The revised launch date, 7 months later than the previous date, included 86 days of schedule reserve, more than required by Goddard Space Flight Center (Goddard) guidelines. As of March 2021, the project has approximately 49 of the 86 days remaining. According to project officials, Goddard guidelines would suggest that a project at this point in development hold 34 days of reserve. However, due to its complexity and lessons learned from prior integration and test work, the project built in additional time above Goddard guidelines and allocated portions of its schedule reserve for each of the remaining key integration and test events, including conducting the last round of environmental tests, deploying and stowing the sunshield, and completing the final observatory build tasks. The project also designated 16 days of the reserve for operations at the launch site in French Guiana. (See fig. 3.)

Figure 3: Key Activities Remaining with Planned vs. Actual Use of Schedule Reserve to Launch



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-21-406

Since revising its launch schedule, the project has consumed schedule reserve beyond what it had allocated for current activities, particularly as a result of recent challenges during sunshield deployment activities. As a result, the project currently has consumed all 35 days of schedule reserve allocated to the first two activities and has begun to use schedule reserve meant for later activities.

Initially, the project used 10 days of schedule reserve—out of 14 set aside for this purpose—following a series of electrical issues that delayed the start of observatory environmental testing and to conduct an additional vibration test to further reduce risk. However, to complete the sunshield deploy and stow activities, the project allocated 21 days, but to date has required 28 days to complete these activities. Specifically, the project used 4 days in late 2020 to address delays in relocating the observatory onto the necessary ground support equipment in the contractor facility for sunshield deploy and stow activities.

In January 2021, approximately 24 days of schedule reserve were consumed to repair several small tears in the sunshield membranes, to install pre-emptive patches in high-wear areas of the sunshield, and to account for lost time due to COVID-19 related impacts. Because the project had used all reserve set aside for the first two activities, it used some of the reserve—3 days to date—budgeted for later activities. This means that the project will have less reserve than planned to complete the observatory final build phase. Moreover, the project still must complete several activities to fully stow the sunshield in preparation for launch and may require additional time to complete this work. Additionally, the project expects to use 7 to 14 days of reserve to address anomalies with two spacecraft transponders. Both units were returned to the vendor for investigation and preliminary causes have been identified.

Project Continues Work on Several Redesigns and Is Monitoring Launch Vehicle Concerns Likely to Delay October 2021 Launch

The project is continuing its efforts on testing and implementing several previously reported redesigns, including two separate efforts to address concerns related to membrane retention devices—key single-point failure items for the observatory—as well as changes to the launch vehicle fairing.[16] Project officials reported that these efforts do not currently pose a schedule threat; however, if efforts do not conclude as expected, they could place additional strain on the project's schedule.

For example, the project has redesigned certain membrane retention devices with stronger materials to address concerns about combined pressures created during launch, which could cause damage. The redesigned devices passed their strength testing and, according to project officials, additional testing to determine whether to incorporate the new design is expected to be complete by April 2021. Additionally, the redundant side of a non-explosive actuator, the firing mechanism within the membrane retention device, failed to release during testing. To

[16]GAO-20-224.

address this issue, the project redesigned the device with thicker restraining wire. The testing program for the redesigned devices concluded in early 2021 and the contractor has begun installing the new devices.

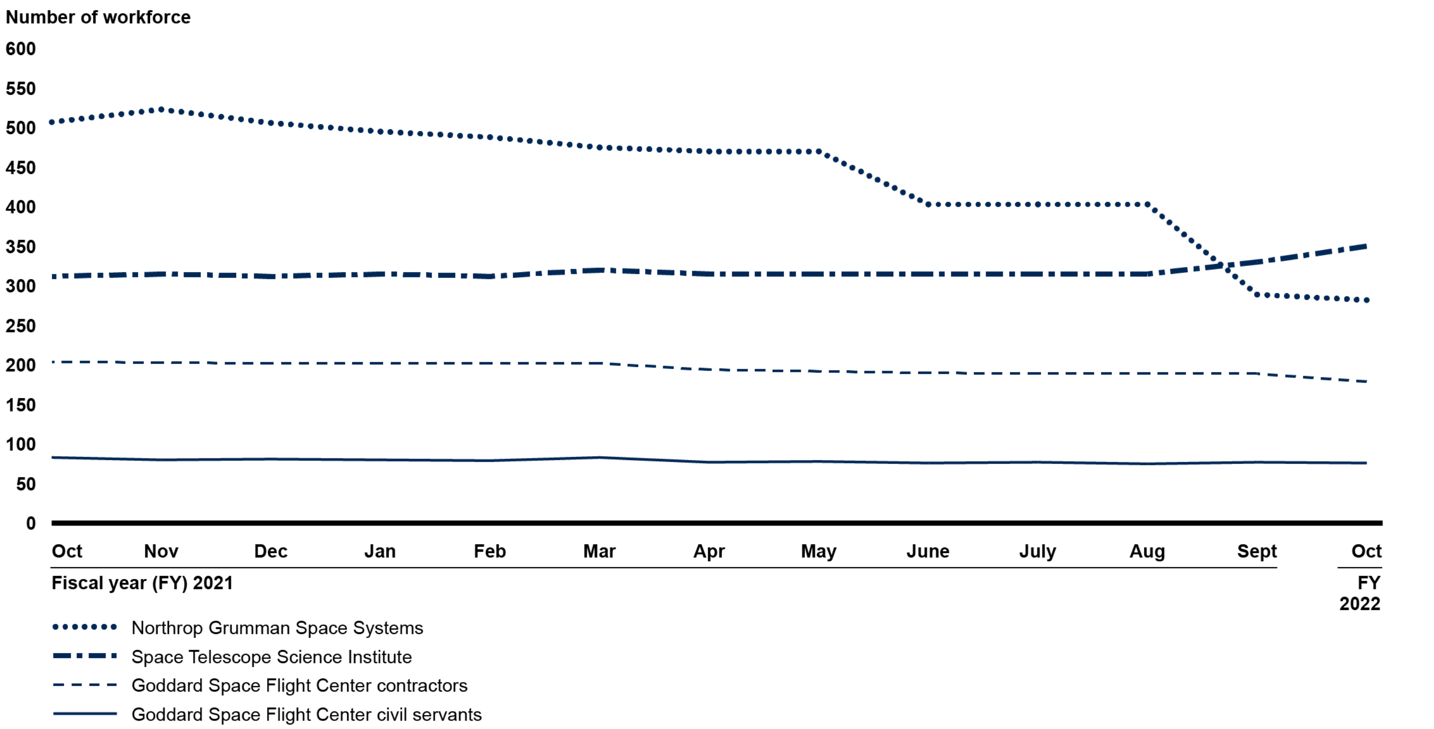
In addition to the membrane retention device redesigns, the project and its international partners implemented two design changes to the Ariane launch vehicle fairing, the part of the launch vehicle that will encapsulate JWST during launch and then release once in space. The design changes were made to address a concern related to trapped air damaging observatory hardware when the fairing separates and depressurizes. Specifically, the project and its partners included actuators to ensure the vent valves would open fully and sealed the fairing's internal honeycomb structure to prevent air leakage into the fairing. Flight data analysis from an Ariane launch in August 2020 with the two design changes incorporated showed that the pressure was reduced by about half of the desired amount. As a result, the project examined its requirements, incorporating more refined data, and determined that the sunshield and other hardware can tolerate more pressure than initially believed. According to project officials, initial data about the system capabilities were based on conservative assumptions. The project applied patches to one of the five sunshield membranes at key locations to increase its strength. The contractor is also analyzing whether residual pressure could damage other parts of the observatory and expects to conclude this work by April 2021.

According to NASA project officials, the JWST launch date will likely be delayed beyond October 2021 due to anomalies discovered in the JWST launch vehicle. These anomalies were identified in recent flights of the Ariane launch vehicle. Ariane launches of this vehicle type are currently postponed until the European Space Agency and Arianespace investigate unexpected vehicle accelerations that occurred when the fairing separated from the launch vehicle on two separate Ariane launches. In both cases, the payloads were successfully placed in orbit. There are two Ariane launches planned before the JWST launch, now expected no earlier than June and August 2021 respectively. Arianespace must demonstrate that the issue has been corrected on at least one of those launches before the JWST launch. As of March 2021, the JWST launch had not been rescheduled; however, project officials assessed the risk that the JWST launch date could be rescheduled as highly likely. The project has received briefings on the investigation's progress from its international partners and is continuing to monitor the situation.

Project's Ability to Meet Cost Commitments Depends on Planned Contractor Workforce Reductions as Launch Date Nears

According to project officials, most of the remaining integration and test work is serial in nature. As a result, workforce is expected to remain at relatively steady levels until the final integration and test tasks are complete. Current NASA projections indicate workforce at Northrop Grumman will begin to decline in mid-2021 as integration and test work concludes and the observatory is prepared for shipping to the launch site in August 2021, while other components of the workforce remain steady through this time frame. (See fig. 4.)

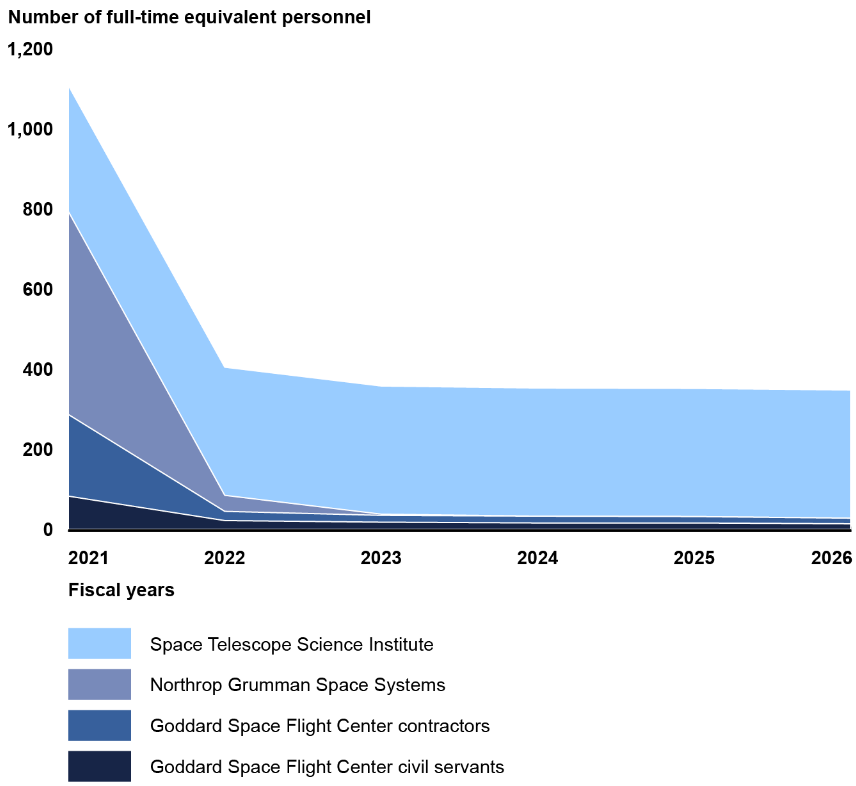
Figure 4: James Webb Space Telescope Projected Workforce Fiscal Year 2021 through Planned Launch



Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-21-406

Given that all major hardware is delivered and integrated at the contractor facility, the Northrop Grumman workforce is the primary cost associated with the project until the observatory is shipped to the launch site in August 2021. Northrop Grumman is projected to hold the largest share of the JWST workforce until that time, after which the Space Telescope Science Institute will constitute the largest portion of staffing through the mission. (See fig. 5.)

Figure 5: James Webb Space Telescope Project Current Projected Annual Workforce



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-21-406

The most recent launch delay, to October 2021, has extended the amount of time that workforce numbers remain at higher levels. However, project officials stated that existing cost reserve is sufficient to cover these additional costs through launch within the project's existing cost commitment. According to project and contractor officials, the contractor used less funding than expected before the launch delay due to several factors including the contractor not receiving a portion of its award fee, cautious initial estimates, and reduced travel during the COVID-19 pandemic.

Additionally, project officials reported that the contractor has become comfortable with the operating conditions under COVID-19, and expect that the contractor can continue working to plan in 2021. However, complicated technical issues, such as those that could arise during the final sunshield deploy/fold/stow exercise, or extended COVID-19 related disruptions beyond those already accounted for through the end of 2020, could create additional schedule delays. This would require the contractor workforce to stay on longer than currently expected and, in turn, strain the project's ability to meet its cost commitments.

JWST Project Expects to Continue Managing Risks after Launch and Is Developing Contingency Plans

Some Risks Managed by the Project Will Continue after Launch

The JWST project has continued to reduce the number of risks it is managing as it approaches its revised launch readiness date. As of February 2021, the project is managing 39 risks—11 fewer than when we reported on JWST in January 2020.[17] Only one of these risks, the fairing issue discussed above, is assessed to present a high overall risk to mission success. Of the 39 risks:

- 27 have been accepted, meaning that no further risk management action needs to be taken for the project to remain within defined risk tolerances.[18]
- Four risks are being watched to determine how remaining integration and test or commissioning activities affect their status. Risk drivers, the elements that contribute most to a given performance risk, may be selected for observation and contingency plans or other deferred actions could be taken based on the results seen during monitoring.

[17] GAO-20-224. See App. II for additional information concerning the number of risks managed by the JWST project through February 2021.

[18] 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). Risk management actions relating to the risk may be needed in the future as conditions change or other departures from planned development may compound the effect of the risk.

- Eight are being mitigated through actions meant to decrease their likelihood or effect on the mission.

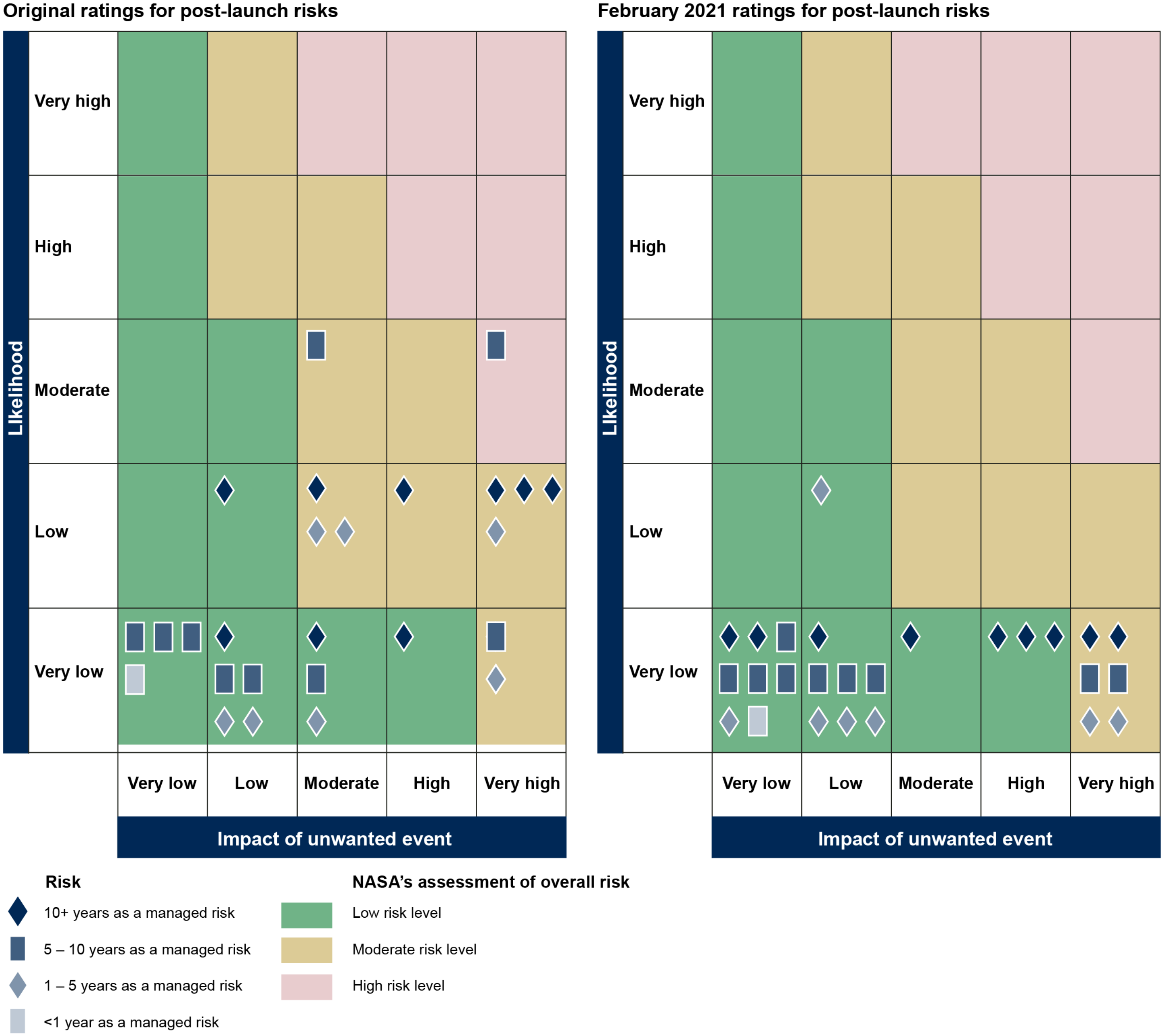
The 12 risks being watched and mitigated by the project include recently identified issues, such as a concern stemming from imprecise directions for tightening fasteners during observatory construction and risks presented by the design of the Ariane launch vehicle fairing, as well as others that the project has managed for more than a decade. The project has assessed all but two risks to be of low or very low likelihood, though some of the remaining risks may have a significant effect on the mission if they were to happen. For instance, eight of the remaining 39 risks are related to at least one of the more than 300 single points of failure within the observatory's design and could result in loss of mission if they were to occur. The two risks that are more likely to occur were added to the project's risk register in December 2020 and January 2021. Specifically, a risk associated with contractor inefficiencies in calendar year 2021 brought on by the COVID-19 pandemic was assessed to have a high likelihood but a low impact on the project. The other risk, related to schedule impacts as a result of Ariane launch vehicle anomalies discussed above, was assessed to be highly likely and having a high potential impact on the mission's schedule, to include the JWST launch date.

The project will continue to monitor, mitigate, and close risks up until launch of the observatory; however, several risks will remain through the commissioning phase and some will be managed through its entire life cycle. Specifically:

- 26 of the 39 remaining will remain open at launch.
- 18 of the 26 will be closed following launch and commissioning of the observatory. For example, risks associated with the sunshield or deployment of mirrors will not be retired until the observatory deploys fully in space.
- The eight remaining risks will remain open during the duration of the entire JWST mission. Among these are risks related to the functionality of the sensitive, near-infrared camera aboard the observatory.

Of the 26 post-launch risks, nine could have a high or very high negative effect on the mission—including total mission loss—but all are assessed to be of a low or very low likelihood. Figure 6 compares the overall risk rating (as a composite of likelihood and potential impact) when each of the 26 post launch risks were first identified to their status in February 2021.

Figure 6: Comparison of Original and February 2021 Ratings for 26 Post-Launch James Webb Space Telescope Project Risks



Source: GAO analysis of JWST project risk data and ratings as of February 2021. | GAO-21-406

Most of the 26 risks that will continue to be monitored by NASA after JWST launches have been managed for 5 or more years and are assessed to carry a lower overall risk level based on their likelihood and potential mission impact than when they were originally identified. For example, as noted in figure 6:

- When originally identified, one post-launch risk was assessed as high and 11 were assessed as moderate overall risks. As of February 2021, none of the post-launch risks are assessed as high and only six are considered to be moderate risks to mission success.
- Several of the post-launch risks are now assessed to be less likely to occur than when originally identified. For example, based on their original assessments, 11 post-launch risks had a low or greater likelihood of occurring. In February 2021, that number was reduced to one risk.

18 of the 26 post-launch risks have been managed by NASA for longer than 5 years; only one has been identified within the last year. This risk is related to the potential loss of functionality in parts of spacecraft related to attitudinal control. This risk has been accepted by the project and is assessed to be very unlikely and of very low impact although it would result in the loss of efficiency in mission operations.

Once commissioning is completed, NASA forecasts all remaining risks following the completion of observatory commissioning to present low overall risk based on likelihood and impact. According to project estimates, all moderate post-launch risks will be resolved during the commissioning process. As noted above, eight risks will remain open throughout the life of the mission. All of these are assessed to be low risk already and, as of February 2021, no mitigating steps are being pursued. All eight are considered very unlikely to occur and most of them are assessed to have low to very low effect on mission success. Two of the eight, however, do present a high risk to mission success should they occur. In both instances a portion of the integrated science instrument module would not function adequately to meet mission requirements.

The Project Is Developing Contingency Plans to Help Ensure Successful Outcomes

The JWST project established a commissioning organization that, among other things, reduces mission risk by developing contingency plans. The project established the commissioning manager position in October 2018 in response to the findings of an independent review board. The role of this position is to provide focus on minimizing commissioning risks with an emphasis on launch, early orbit, observatory deployments, and other steps needed to ensure the observatory is able to complete its mission.

The commissioning organization, established in April 2019, works under the commissioning manager with engineering leads to ensure consistency among the engineering, integration and test, and operational stakeholders involved in commissioning planning and execution.

Among its duties, the JWST commissioning organization identifies contingency responses to unwanted events during the mission, capabilities required to respond to contingency situations or reduce risk, and risk reduction opportunities in operations. The organization has monitored the results of integration and testing activities and worked with other project stakeholders to ensure commissioning planning takes into account identified risks and design adjustments. For example, the project determined that a new battery should be installed on the observatory. The more modern battery provides for increased battery life and, thus, more capability during commissioning to address anomalies and more flexibility when developing plans to address contingencies. Project officials told us that only a few design changes have been needed as a result of the planned commissioning process. Among these are software updates that control the speed of certain mirror adjustments and capabilities that will allow the observatory to be spun and vibrated to alleviate potential, unknown deployment anomalies.

Further, the JWST commissioning organization also conducted a series of audits covering nine broad areas, which, among other things, helped inform contingency planning. This process, which officials noted as unique to the JWST project, was initiated to help ensure that commissioning officials had a complete and current understanding of the observatory's different parts and capabilities, especially in areas that had not been the focus of integration and testing activities recently. The audits were performed by representatives from NASA, Northrop Grumman, and the Space Telescope Science Institute between April and September 2020. The audits resulted in 152 items for follow-up including expanding or clarifying documentation and commissioning timeline activities, additional assessments, and development of contingency plans, among others. According to project officials, the results were shared with the JWST standing review board comprised of independent technical experts and all actions are expected to be completed ahead of the flight operations review scheduled for April 2021.

According to project officials, contingency planning covers a broad range of scenarios, and not all of the 39 open risks currently managed by the project requires a specific plan. As of November 2020, the JWST project developed 207 contingency plans for a variety of issues that may be faced during launch, commissioning, and operation of the observatory. According to officials, they prioritize open project risks and other time critical anomaly scenarios that could result in mission failure and significant mission degradation for contingency planning. At least seven of the contingency plans are directly related to open risks that are managed by the project and present significant potential consequences. According to officials, contingency plans to address all risks identified by the program may not be feasible because there may be no practical on-orbit way to mitigate them. Officials stated that those risks without an associated contingency plan are generally isolated to specific subsystems, may have redundant capabilities to minimize effect, or would not result in loss of mission or severe degradation in mission, though they could affect aspects of the mission or its duration. Further, project officials told us that determining the best response to a risk item may benefit from or require on-orbit data.

Agency Comments

We provided a draft of this report to NASA for review and comment. NASA told us that they had no comments on the draft report.

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 russellw@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.

W. William Russell
Director, Contracting and National Security Acquisitions

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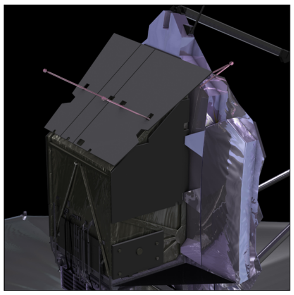
Committee on Science, Space and Technology
House of Representatives

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



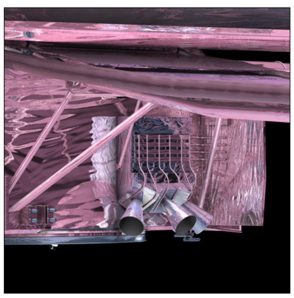
Integrated Science Instrument Module
Acronym: ISIM
Contractor/Center: Goddard Space Flight Center
Description: Combines the 4 instruments

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

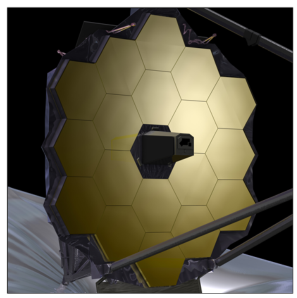
Near Infrared Spectrograph
Acronym: NIRSpec
Contractor/Center: European Space Agency
Description: Science instrument

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

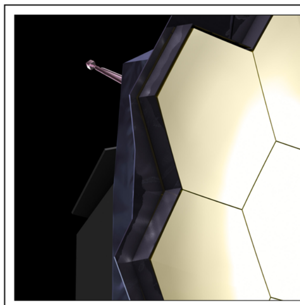
Near Infrared Camera
Acronym: NIRCam
Contractor/Center: University of Arizona
Description: Science instrument and Wave Front Sensor



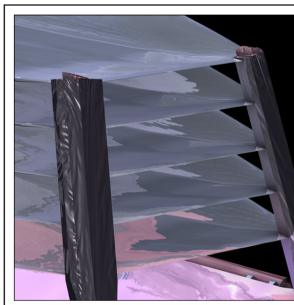
Spacecraft
Contractor/Center: Northrop Grumman Space Systems
Description: Contains the power, communications, and avionics needed to operate the observatory. Contains the cryocooler needed to achieve MIRI operational temperatures approximating 6.7 Kelvin



Optical Telescope Element
Acronym: OTE
Contractor/Center: Northrop Grumman Space 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 Space 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 (data and images). | GAO-21-406

Appendix II: James Webb Space Telescope Project Risks

As of February 2021, the James Webb Space Telescope project had identified and managed 175 risks and had closed 136 of them. About one-third of these risks pertain to aspects of the integrated science instrument module, which contains the sensitive instruments needed to capture data. Table 1 provides an overview of the number of risks managed by the program during the observatory's life cycle thus far.

Table 1: Risks Managed by the James Webb Space Telescope Project as of February 2021

Category	Risks closed before observatory integration and test[a]	Risks carried into observatory integration and test	Risks opened during observatory integration and test	Risks closed during observatory integration and test	Remaining Risks as of February 2021
Mission System Engineering	8	15	4	16	3
Integrated Science Instrument Module (ISIM)	32	25	3	15	13
Optical Telescope Element (OTE)	6	18	3	15	6
Spacecraft Element	8	2	0	1	1
Sunshield	2	5	2	2	5
Cryocooler	5	5	0	5	0
Integrated OTE and ISIM	4	8	0	8	0
Observatory Integration and Test	0	3	9	6	6
Ground Systems and Operations	1	2	0	1	1
Safety and Mission Assurance	0	2	1	1	2
Contractor-related	0	0	1	0	1
Launch Vehicle	0	0	1	0	1
Total	**66**	**85**	**24**	**70**	**39**

Source: GAO analysis of NASA risk data | GAO-21-406

[a]Observatory integration and test refers to integration of OTE with ISIM and integration of spacecraft subassemblies beginning in April 2016.

Appendix III: GAO Contact and Staff Acknowledgments

GAO Contact

W. William Russell, (202) 512-4841 or russellw@gao.gov

Staff Acknowledgments

In addition to the contact named above, Raj Chitikila (Assistant Director), Carrie Rogers, Jay Tallon, and Thomas Twambly made key contributions to this report. Assistance was also provided by Lorraine Ettaro, Pete Anderson, Jason Lee, Christine Pecora, Jim Rice, Roxanna Sun, and Alyssa Weir.

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