United States Government Accountability Office

GAO

Report to Congressional Committees

December 2012

# JAMES WEBB SPACE TELESCOPE

# Actions Needed to Improve Cost Estimate and Oversight of Test and Integration


GAO-13-4

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## Actions Needed to Improve Cost Estimate and Oversight of Test and Integration

GAO Accountability * Integrity * Reliability

Highlights

Highlights of GAO-13-4, a report to congressional committees

### Why GAO Did This Study

JWST is one of NASA's most expensive and technologically advanced science projects, intended to advance understanding of the origin of the universe. In 2011, JWST was rebaselined with a life cycle cost estimate of $8.8 billion and a launch readiness date in October 2018—almost nine times the cost and more than a decade later than originally projected in 1999. Concern about the magnitude of JWST's cost increase and schedule delay and their effects on NASA's progress on other high-priority missions led conferees for the Consolidated and Further Continuing Appropriations Act, 2012, to direct GAO to report on the project. Specifically, GAO assessed (1) the extent to which NASA's revised cost and schedule estimates are reliable based on best practices, (2) the major risks and technological challenges JWST faces, and (3) the extent to which NASA has improved oversight of JWST. To do this, GAO compared NASA's revised cost and schedule estimates with best practice criteria, reviewed relevant contractor and NASA documents, and interviewed project and contractor officials.

### What GAO Recommends

GAO recommends NASA take six actions including, among others, to take steps to improve its cost estimate; to conduct an additional, earlier independent review of test and integration activities; and to develop a long-term oversight plan that anticipates planned travel budget reductions. In commenting on a draft of this report, NASA fully or partially concurred with the recommendations citing ongoing efforts, but GAO believes some do not go far enough.

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### What GAO Found

The National Aeronautics and Space Administration (NASA) has provided significantly more time and money to the James Webb Space Telescope (JWST) than previously planned and expressed high confidence in the project's new baselines. Its current cost estimate reflects some features of best practices for developing reliable and credible estimates. For example, the estimate substantially meets one of four cost characteristics—comprehensive—that GAO looks for in a reliable cost estimate, in part because all life cycle costs were included. The estimate, however, only partially met the other three characteristics—well documented, accurate, and credible—which detracts from its reliability. For example, the estimate's accuracy, and therefore the confidence level assigned to the estimate, was lessened by the summary schedule used for the joint cost and schedule risk analysis because it did not provide enough detail to determine how risks were applied to critical project activities. The estimate's credibility was also lessened because officials did not perform a sensitivity analysis that would have identified key drivers of costs, such as workforce size. Program officials believe that it would have been difficult to fully address all best practice characteristics. GAO believes there is time to improve the estimate and enhance the prospects for delivering the project according to plan.

Project officials report that the JWST schedule has 14 months of reserve, which meets Goddard guidance for schedule reserve; however, only 7 of the 14 months are likely to be available for the last three of JWST's five complex integration and test efforts. GAO's prior work shows that the integration and test phases are where problems are commonly found and schedules tend to slip. Given that JWST has a challenging integration and test schedule, this could particularly be likely. The project has made some significant progress in the past year, notably successfully completing development of the 18 primary mirror segments—considered JWST's top technical risk. Nevertheless, ongoing challenges are indicative of the kinds of issues that can require significant effort to address. For example, instrument challenges have delayed the first integration and test effort. In addition, key long-term risks on subsystems with a significant amount of work remaining will not be retired until 2016. Currently, NASA's plan for project oversight calls for one independent mission-level system integration review about 13 months before launch. While this is consistent with what NASA requires for its projects, this approach may not be sufficient for a project as complex as JWST.

JWST has taken several steps to improve communications and oversight of the project and its contractors—such as taking over responsibility for mission systems engineering from the prime contractor; instituting meetings that include various levels of NASA, contractor, and subcontractor management; and implementing a new risk management system to allow for better tracking of risks. The enhancements to the oversight of the project are steps in the right direction, but it will take time to assess their effectiveness and ensure that the efforts are sustained by the project in the future. Reductions in travel budgets, however, could require the project to adjust the oversight approach that was adopted as a result of the replan. Additional reductions in travel budgets are anticipated in future years, but officials do not have a plan to address such reductions and their potential impact on continuing the current oversight approach.

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Figures



**Abbreviations**

| | |
|---|---|
| CSA | Canadian Space Agency |
| ESA | European Space Agency |
| FGS | Fine Guidance Sensor |
| ICRP | Independent Comprehensive Review Panel |
| ISIM | Integrated Science Instrument Module |
| JCL | Joint Cost and Schedule Confidence Level |
| JWST | James Webb Space Telescope |
| KDP | key decision point |
| MIRI | Mid-Infrared Instrument |
| NASA | National Aeronautics and Space Administration |
| NIRCam | Near-Infrared Camera |
| NIRISS | Near-Infrared Imager and Slitless Spectrograph |
| NIRSpec | Near-Infrared Spectrograph |
| NPR | NASA Procedural Requirements |
| OTE | Optical Telescope Element |
| OTIS | Optical Telescope Element and Integrated Science Instrument Module |

GAO
Accountability * Integrity * Reliability

**United States Government Accountability Office**
**Washington, DC 20548**

December 3, 2012

Congressional Committees

The James Webb Space Telescope (JWST) is one of the National Aeronautics and Space Administration's (NASA) most expensive and technologically advanced science projects. It is intended to revolutionize our understanding of star and planet formation and advance the search for the origins of our universe. The project has been hampered by ineffective management, unrealistic estimates of costs, and insufficient resources, and is projected to cost significantly more and to take much longer to complete than expected when it was authorized to proceed in 1999. In 2011, JWST was rebaselined with a lifecycle cost estimate of $8.8 billion and a launch date in October 2018, which is almost nine times the cost and more than a decade later than originally projected. The magnitude of JWST's cost increase and schedule delay has and will continue to have a major effect on NASA's ability to implement or begin high-priority science missions for years to come.

NASA has expressed high confidence in being able to execute the project within its new cost and schedule baselines, and officials report that the project is being executed to its revised estimates in the year since the rebaseline. The project, however, is less than halfway through its development with known and unknown technical risks and challenges remaining to be addressed. The on-time and on-budget delivery of JWST is a high congressional priority. In November 2011, the Joint Explanatory Statement of the Committee of Conference for the Consolidated and Further Continuing Appropriations Act, 2012, recommended that JWST's formulation and development costs, not including the cost to operate the mission after launch, be no more than $8 billion. The conferees also directed 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. This report responds to that direction. Specifically, we assessed (1) the extent to which NASA's revised cost and schedule estimates are reliable based on GAO best practices, (2) the major risks and technological challenges the JWST project faces, and (3) the extent to which NASA has improved the oversight of the JWST project.

Our approach included an examination of the revised cost and schedule estimates NASA developed during the replanning process using GAO's best practice criteria.[1] This included review of documentation of the inputs that supported the detailed cost and schedule estimates used by decision-makers to rebaseline the program and interviews with project officials involved in developing the estimates. We also reviewed the proposal from the JWST prime contractor used as input to the replan and interviewed contractor officials. We did not assess the most current JWST integrated master schedule because of ongoing negotiations for contract modifications associated with the replan. To identify the major short and long term risks and technological challenges facing the project, we interviewed project officials for the major subsystems as well as contractor officials. We also reviewed the project's risk database, monthly status reviews, and other documentation provided by the project officials. To understand the steps NASA implemented to improve the oversight being performed on the project, we interviewed project and contractor officials and reviewed documentation from independent reviews prior to the replan and actions taken by NASA in response. We also interviewed the Director of NASA's Office of Evaluation concerning a recent independent review of the JWST project performed by his office. We took appropriate steps to address data reliability, such as clarifying data discrepancies and corroborating NASA-generated data with other sources where applicable. NASA provided comments and technical clarifications on a draft of this report, which were incorporated as appropriate. Appendix I contains detailed information on our scope and methodology.

We conducted this performance audit from February 2012 to December 2012 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.

[1]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); and *GAO Schedule Assessment Guide: Best Practices for Project Schedules,* GAO-12-120G (Washington, D. C.: May 30, 2012).

## Background

Initially referred to as the "Next Generation Space Telescope," JWST is a large deployable, infrared-optimized space telescope intended to be the successor to the aging Hubble Space Telescope. JWST is designed to be a 5-year mission to find the first stars and trace the evolution of galaxies from their beginning to their current formation, and is intended to operate in an orbit approximately 1.5 million kilometers—or 1 million miles—from the Earth. In a 2001 decadal survey, the National Research Council rated the JWST as the top-priority new initiative for astronomy and physics. With its 6.5-meter primary mirror, JWST will be able to operate at 100 times the sensitivity of the Hubble Space Telescope. A tennis-court-sized sunshield will protect the mirrors and instruments from the sun's heat to allow the JWST to look at very faint infrared sources. The Hubble Space Telescope operates primarily in the visible and ultraviolet regions.[2]

## History of Cost Growth and Schedule Delays

JWST has experienced significant increases to project costs and schedule delays. Prior to being approved for development, cost estimates of the project ranged from $1 billion to $3.5 billion with expected launch dates ranging from 2007 to 2011. In March 2005, NASA increased the JWST's life-cycle cost estimate to $4.5 billion and slipped the launch date to 2013. We reported in 2006 that about half of the cost growth was due to schedule slippage—a 1-year schedule slip because of a delay in the decision to use a European Space Agency-supplied Ariane 5 launch vehicle and an additional 10-month slip caused by budget profile limitations in fiscal years 2006 and 2007. More than a third of the cost increase was caused by requirements and other changes. An increase in the program's contingency funding accounted for the remainder—about 12 percent—of the growth. NASA Headquarters chartered an Independent Review Team to evaluate the project that same year. In April 2006, the review team's assessment confirmed that the program's technical content was complete and sound, but expressed concern over the project's contingency reserve funding—funding used to mitigate issues that arise but which were previously unknown—reporting that it was too low and phased in too late in the development life cycle. The team reported that for a project as complex as the JWST, a 25 to 30

[2]The electromagnetic spectrum is the wavelengths of all the visible and invisible light. The infrared part of the spectrum, also known as radiant heat, has wavelengths that go from about 0.75 microns to a few hundred microns. The Hubble is designed to operate primarily in the ultraviolet and visible wavelengths of the spectrum from 0.1 to 0.8 microns. Humans cannot see in the ultraviolet region.

percent total contingency was appropriate. At that time, JWST's total contingency was about 19 percent. The team cautioned that this contingency compromised the project's ability to resolve issues, address risk areas, and accommodate unknown problems. The team also concluded that the 2013 launch date was not viable for the project based on its anticipated budget. It recommended that before the project was formally approved for development and baselined, NASA should take steps to provide the JWST project with adequate time-phased reserve funding to secure a stable launch date. Additional reserves were added and the project was baselined in April 2009 with a life-cycle cost estimate of $4.964 billion and a launch date in June 2014.

Shortly after JWST was approved for development and its cost and schedule estimates were baselined, project costs continued to increase. In 2010, Senator Barbara Mikulski, chair of the Senate Committee on Appropriations, Subcommittee on Commerce, Justice, Science, and Related Agencies, asked NASA to initiate another independent review in response to the project's cost increases and reports that the June 2014 launch date was in jeopardy. The Independent Comprehensive Review Panel (ICRP) was commissioned by NASA and began its review in August 2010. In October 2010, the ICRP issued its report and cited several reasons for the project's problems including management, budgeting, oversight, governance and accountability, and communication issues.[3] The panel concluded JWST was executing well from a technical standpoint, but that the baseline funding did not reflect the most probable cost with adequate reserves in each year of project execution, resulting in an unexecutable project. The review panel recommended that additional resources be considered along with organizational and management restructuring. Following this review, the JWST program underwent a replan in 2011. In November 2011, the JWST project was reauthorized, but not before it was recommended for termination by the House Appropriations Committee. On the basis of the replan, NASA announced that the project would be rebaselined at $8.835 billion—a 78 percent increase to the project's life-cycle cost from the confirmed baseline—and would launch in October 2018—a delay of 52 months. The revised life-cycle cost estimate included 13 months of funded schedule reserve. In the President's Fiscal Year 2013 budget request, NASA reported a 66

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

percent joint cost and schedule confidence level associated with these estimates. A joint cost and schedule confidence level (JCL) is the process NASA uses to assign a percentage to the probable success of meeting cost and schedule targets and is part of the project's estimating process.

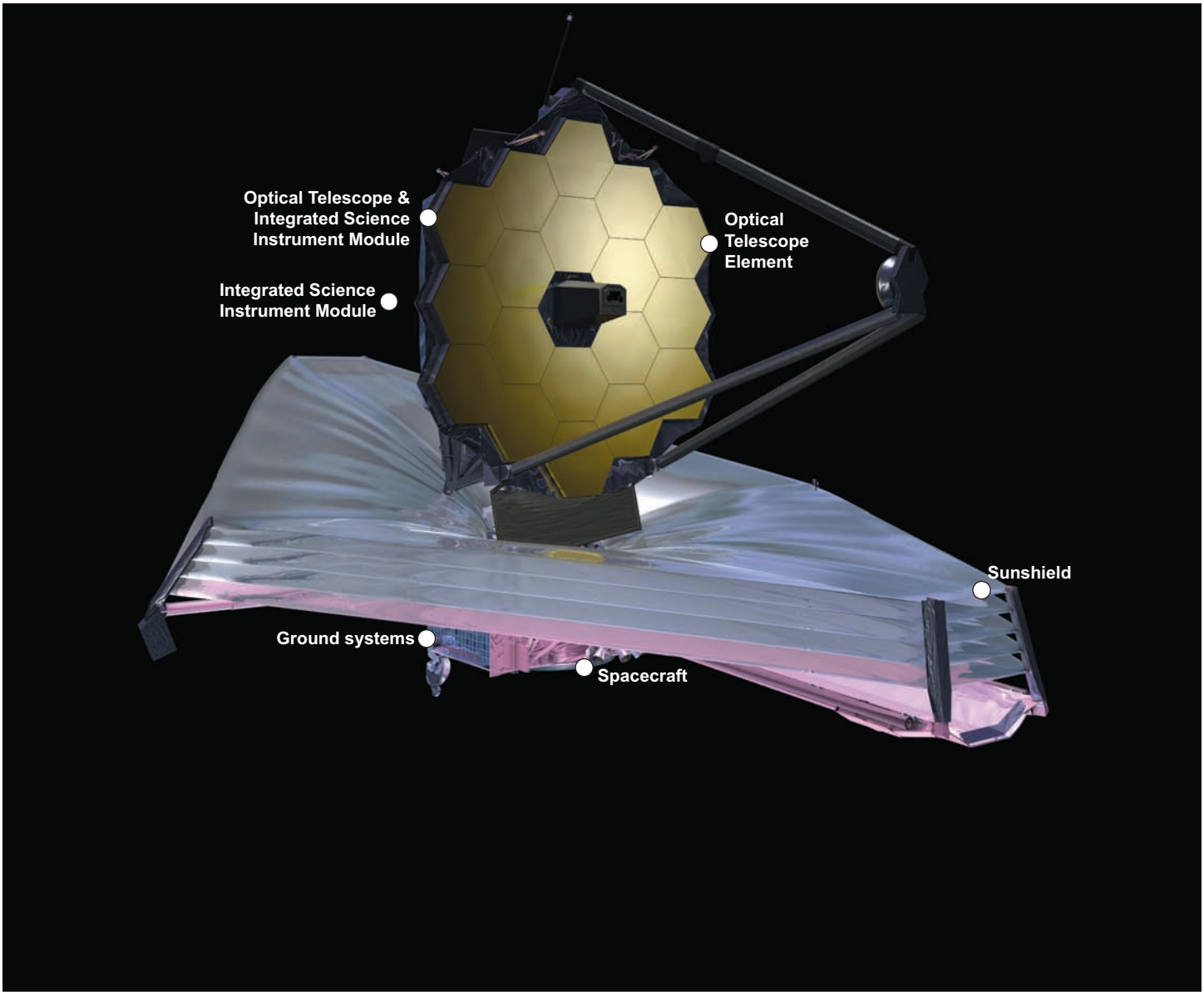
## Current JWST Organization

The JWST project is divided into three major segments: the launch segment, the ground segment, and the observatory segment. The launch segment is primarily provided by the European Space Agency (ESA), which is contributing the Ariane 5 launch vehicle and launch site operations in French Guiana. The ground segment will be responsible for collecting the data obtained by JWST in space and making it usable for scientists and researchers. This includes the development of software that will translate data into usable formats as well as operation of the software once the telescope is in space. The Space Telescope Science Institute, operated by the Association of Universities for Research in Astronomy (AURA) on a contract awarded by NASA, which currently performs science operations for the Hubble Space Telescope, is developing the science and operations and flight operations center for JWST and will conduct the first 6 months of flight and science operations. The NASA contract with the Space Telescope Science Institute extends through the first 6 months of JWST operations. A contract to manage the long term operations of JWST is planned to be awarded approximately 2 years prior to launch. The observatory segment will be launched into space and includes five major subsystems.[4] These subsystems are being developed through a mixture of NASA, contractor, and international partner efforts. See figure 1.

[4]The hardware configuration created when the Optical Telescope Element and the Integrated Science Instrument Module are integrated, referred to as OTIS, is not considered a subsystem by NASA, but we categorize it as such for ease of discussion.

**Figure 1: James Webb Space Telescope**

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

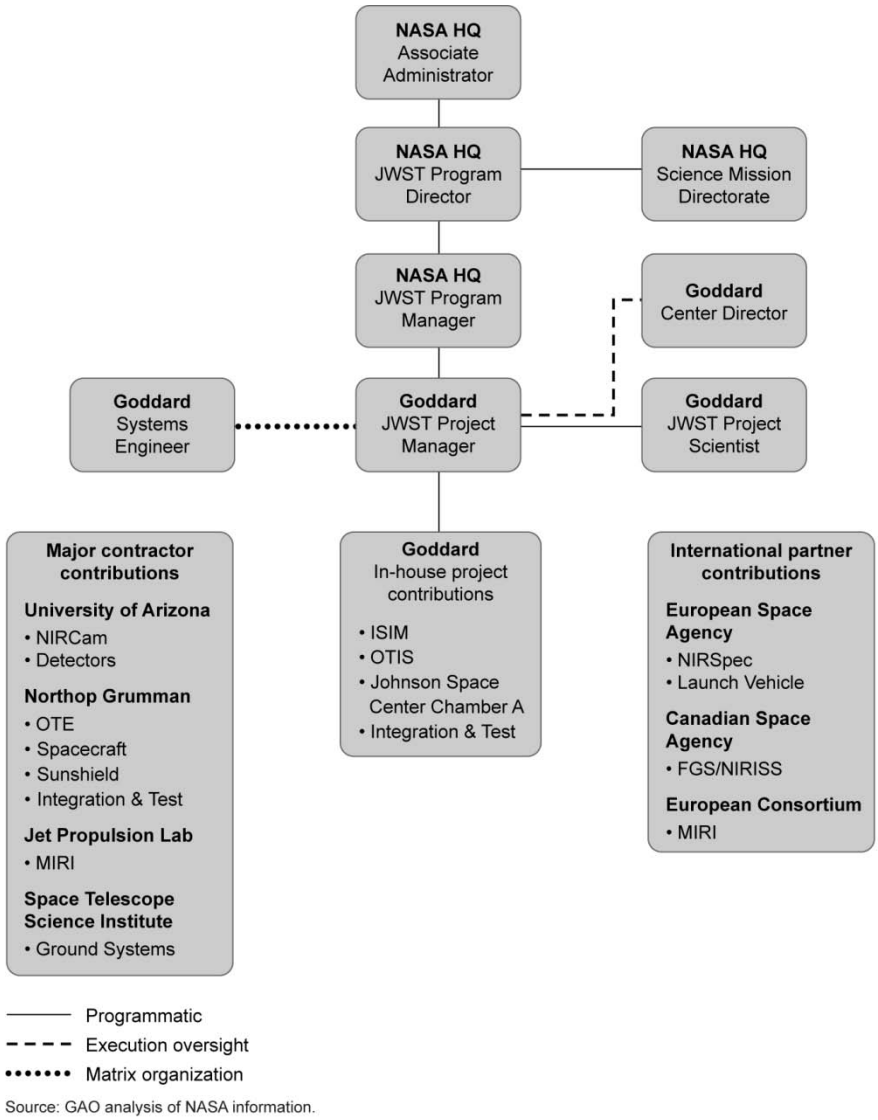



Sources: GAO (analysis); NASA (data and images).

JWST is a single project program reporting directly to the NASA Associate Administrator for programmatic oversight and to the Associate Administrator for the Science Mission Directorate for technical and analysis support.[5] Goddard Space Flight Center is the NASA center responsible for the management of JWST. See figure 2 for the current JWST organizational chart.

[5]A project typically reports to a program within a mission directorate, such as the Science Mission Directorate. A similar reporting structure was also instituted in the past with both the Hubble Space Telescope and the Mars Exploration Program when they began experiencing significant cost and schedule issues. For JWST, the change was made in response to recommendations from the ICRP.

**Figure 2: Organizational Chart for the JWST Program**




Source: GAO analysis of NASA information.

## Revised JWST Cost Estimate Is Not Fully Consistent with Best Practices for Reliable and Credible Estimates and the Integrated Master Schedule Is Not Finalized

Our analysis of JWST's revised cost estimate showed that it is not fully consistent with best practices for developing reliable and credible estimates, although project officials took some steps in line with best practices in the development of the estimate. For example, as part of its cost estimation process, the project conducted a joint cost and schedule risk analysis, or joint cost and schedule confidence level (JCL), which assigned a 66 percent confidence level to the estimate.[6] In addition, we found that the cost estimate included all life cycle costs for the project. Although NASA's methods for developing the JWST cost estimate reflect some features of best practices, our review of the estimate showed that based on best practice criteria, it did not fully meet the four characteristics of a reliable estimate. See figure 3.

[6]The JCL is a quantitative probability analysis that requires the project to combine its cost, schedule, and risks into a complete quantitative picture to help assess whether the project will be successfully completed within cost and on schedule. NASA introduced the analysis in 2009, and it is among the agency's initiatives to reduce acquisition management risk. The move to probabilistic estimating marks a major departure from NASA's prior practice of establishing a point estimate and adding a percentage on top of that point estimate to provide for contingencies. NASA's procedural requirements state that Mission Directorates should plan and budget programs and projects based on a 70 percent JCL, or at a different level as approved by the Decision Authority—which in the case of the JWST project would be the Agency Program Management Council—and any JCL approved at less than 70 percent must be justified and documented. NASA Procedural Requirements (NPR) 7120.5E, *NASA's Space Flight Program and Project Management Requirements*, paragraph 2.4.4 (Aug. 14, 2012).

**Figure 3: Summary of Results of GAO Assessment of JWST Cost Estimate Based on Best Practices Criteria**

| Characteristics | Best Practices Criteria | Overall assessment |
|---|---|---|
| Comprehensive | Include costs of the program over its full life-cycle, provide a level of detail appropriate to ensure that cost elements are neither omitted nor double-counted, and document all cost-influencing ground rules and assumptions. | ◕ |
| Well documented | Be supported by detailed documentation describing:<br>• the purpose of the estimate,<br>• the program background and system description,<br>• the scope of the estimate,<br>• the ground rules and assumptions,<br>• all data sources,<br>• estimating methodology and rationale, and<br>• the results of the risk analysis.<br>This documentation should show how the data used to derive the estimate can be traced back to, and verified against, their sources. | ◑ |
| Accurate | Be based on an assessment of most likely costs (adjusted for inflation), documented assumptions, and historical cost estimates and actual experiences on other comparable programs.<br>Be checked for accuracy, double counting, and omissions.<br>Be updated to reflect any changes. | ◑ |
| Credible | Discuss any limitations of the analysis because of uncertainty, or biases surrounding data or assumptions. Risk and uncertainty analysis should be performed to determine the level of risk associated with the estimate.<br>Have results that are cross-checked against an independent estimate. | ◑ |

● Met
◕ Substantially met
◑ Partially met
◔ Minimally met
○ Not met

Source: GAO analysis of NASA data.

Note: Met: NASA provided complete evidence that satisfies the entire criterion; Substantially Met: NASA provided evidence that satisfies a large portion of the criterion; Partially Met: NASA provided evidence that satisfies about half of the criterion; Minimally Met: NASA provided evidence that satisfies a small portion of the criterion; and Not Met: NASA provided no evidence that satisfies any of the criterion. See appendix III for our evaluation of JWST's cost estimate process.

Specifically, the project's estimate was found to substantially meet the best practice criteria for being comprehensive, and the remaining three characteristics of being well documented, accurate, and credible were found to be only partially met. For example, the accuracy of the cost estimate, and therefore the confidence level assigned to the estimate, was lessened by the schedule used in the JCL analysis because it prevented us from, among other things, identifying the activities that were on the critical path—defined as time associated with activities that drive the overall schedule. The credibility of the estimate was lessened

because project officials did not perform a sensitivity analysis that would have identified key drivers of costs, such as workforce size. Although NASA is not required to adhere to these best practices, our prior work has shown that not following best practices for cost estimating can make the cost estimate less reliable, putting projects at risk of experiencing cost overruns, missed deadlines, and performance shortfalls.[7] The best practices stem from practices federal cost estimating organizations and industry use to develop and maintain reliable cost estimates, including the Department of Defense and NASA. According to program officials, it would have been difficult, if not impossible, for the project to have met all of the best practice criteria given the complexity of the project and that some elements of the project are quite mature in their development. Instead, the program manager stated that the project followed a tailored process to develop the cost estimate that was appropriate for the project. Furthermore, officials report the project is currently meeting a majority of its milestones and executing as planned to the revised estimates for the JWST.

**Comprehensive:** The JWST cost estimate substantially met the criteria for being comprehensive because it included all life-cycle costs, documented cost-influencing ground rules and assumptions, and used a work breakdown structure, or the structure used to define in detail the work necessary to accomplish its objectives, that is detailed and traceable to the cost of each work element and the contract statement of work.[8] The cost estimate is not considered fully comprehensive, however, because we were unable to align the schedule to the cost estimate and could not align all of the subcontractor work to the work breakdown structure of the cost estimate. Although NASA officials believe that the project has visibility into, and can map, subcontractor activities, we were unable to confirm that cost elements were neither omitted nor double counted. In addition, we were unable to map the project's earned value management data to the work breakdown structure because information between the

[7]GAO-09-3SP.

[8]A work breakdown structure reflects the requirements and what must be accomplished to develop a program, and it provides a basis for identifying resources and tasks for developing a program cost estimate. The work breakdown structure should be used to define all program activities and tasks to ensure that the schedule encompasses the entire work.

two was not compatible.[9] Finally, although the project outlined and documented the ground rules and assumptions, we were unable to determine whether risks associated with any assumptions were identified and traced to specific elements.

**Well documented:** The JWST cost estimate only partially met the criteria for being well documented because it did not include a step-by-step description of how the estimate was developed, the raw data used to develop the estimate, or the calculations and estimating methodology for specific cost elements of the work breakdown structure. Without good documentation, a cost analyst unfamiliar with the program will not be able to replicate the estimate, because he or she will not understand the logic behind it. Good documentation, for example, assists management and oversight in assessing the credibility of the estimate, helps to keep a history of reasons for cost changes and to record lessons learned, defines the scope of the analysis, and answers questions about the approach or data used to create the estimate. Project documentation, however, does provide evidence that NASA management reviewed and accepted the cost estimate because managers were briefed on the technical aspects of the estimate and were provided an overview of the joint cost and schedule risk analysis that was conducted.

**Accurate:** The JWST cost estimate only partially met the criteria for being accurate because the projected costs of schedule reserve did not reflect actual data, the summary schedule used to derive the JCL prevented us from sufficiently understanding how risks were incorporated, and the project did not provide evidence that it regularly updates the estimate or plans to conduct another JCL. For example, using historical actual cost data from Northrop Grumman, we estimated that 13 months of schedule reserve is likely to be $204 million instead of NASA's estimate of $121 million—a potential underestimation of 69 percent related to the schedule reserve. Project officials, however, believe they have adequate reserves available to offset any underestimation. In addition, the summary

[9]Earned value management is a project management tool that integrates the technical scope of work with schedule and cost elements and compares the value of work accomplished in a given period with the value of the work expected in that period. When used properly, earned value management can provide objective assessments of project progress, produce early warning signs of impending schedule delays and cost overruns, and provide unbiased estimates of anticipated costs at completion. As a best practice the work breakdown structure should match the schedule, cost estimate, and earned value management system at a high level so that it clearly reflects the work to be done.

schedule the project used as an input to the JCL, although deemed acceptable by NASA, contained many long-duration activities, some with 1,000 days or more. Because of these long durations in the summary schedule used for the JCL, the lack of detail prevented us from identifying the activities that were on the critical path, as well as which risks were applied to remaining activities.[10] As a result, there is no way to ensure that risks were appropriately assigned to activities in the schedule to account for the impact of the risks during the JCL analysis.

Finally, it was unclear whether the cost estimate was regularly updated to reflect material changes in actual costs and in the project itself, such as when schedules or other assumptions change, due to a lack of detailed documentation for the cost estimate. Project officials stated that in keeping with NASA policy they do not plan, nor are they required, to conduct another JCL analysis. GAO's cost estimating best practices call for estimates to be continually updated through the life of the project, ideally every month as actual costs are reported in earned value management reports, and that a risk analysis and risk simulation exercise—like the JCL analysis—be conducted periodically through the life of the program, as risks can materialize or change throughout the life of a project. Unless properly updated on a regular basis, the cost estimate cannot provide decision makers with accurate information to assess the current status of the project. NASA officials state that the life-cycle cost estimate is updated annually for the budgeting process, and that historical records such as earned value data were used to develop the estimate. They also stated that this information is updated in several different documents being provided to management; however, we were unable to determine how this information was used in updating the cost estimate on a regular basis.

**Credible:** The JWST cost estimate only partially met the criteria for being credible because project officials did not adequately test and verify the reasonableness of the cost estimate and the schedule used in conducting the JCL did not have a valid critical path and contained durations that were too long to properly account for risks. For example, project officials said they did not perform a sensitivity analysis for the cost estimate. A sensitivity analysis identifies key elements that drive cost and permits

[10]A summary schedule is derived from the integrated master schedule and is often used in a JCL analysis when, for example, time or resources needed to simulate the full detailed schedule are limited.

analysis of different outcomes and is often used to develop cost ranges and risk reserves. NASA officials stated that the largest cost driver for the JWST project is the size of the workforce, which could have been subjected to a sensitivity analysis; yet, the cost model did not include a sensitivity analysis that would show how staff increasing or decreasing over time affects cost. In addition, NASA officials believe that all risks were sufficiently accounted for when conducting the JCL, however, the software used to conduct the JCL analysis does not recognize certain risks that officials had placed on activities in the project schedule and, therefore, some risks were discarded during the simulation.

The schedule used to conduct the JCL was also summarized at such a high level that the durations were too long to effectively model the risks. For example, one of the activities that drove the launch date was over 4 years in duration and should have been broken down further prior to conducting the simulation. Moreover, the critical path in the JCL schedule consisted of six level of effort activities all with the same duration of 2,238 days in length.[11] Level of effort activities should never be on the critical path because support activities should never drive any milestone finish date. As a result of the schedule used in the JCL not fully meeting best practices, we question the results of the analysis. Furthermore, the risk of having to carry the JWST workforce to support the project if delayed was not included since a sensitivity analysis was not performed. Project officials report that, instead, risk associated with the workforce was factored in when establishing cost reserves.

In addition, project officials did not commission an independent cost estimate, which is considered one of the best and most reliable estimate validation methods because it shows whether other estimating procedures produce similar results, and it provides an independent view of expected program costs that tests the program office's estimate for reasonableness.[12] An estimate that has not been reconciled with an independent cost estimate has an increased risk of being underfunded

[11]Level of effort activities are those activities that have no measurable output and cannot be associated with a physical product or defined deliverable. These activities are typically related to management and other oversight that continues until the detailed activities they support have been completed.

[12]An independent cost estimate is conducted by a group outside the acquiring organization that uses the same detailed technical information as the program estimate to determine whether other estimating methods produce similar results.

because the independent cost estimate provides an objective and unbiased assessment of whether the project estimate can be achieved. Notably, however, project officials provided evidence that an independent cost assessment was done for the project at the request of the JWST Standing Review Board, the independent review team for the project, and the assessment was within 2 percent of the project's estimated cost for the rebaseline. Project officials contend that the approach they used in developing the life-cycle cost estimate for the project is more accurate than the types of approaches often used to develop and independent estimate.

## Complete Schedule Not Finalized; Full Assessment of Schedule Needed

We did not conduct a full schedule assessment to determine the reliability of the revised schedule based on best practices due to on-going contract negotiations.[13] The project has an integrated master schedule developed as part of the replan; however, it is not finalized because major contract modifications have yet to be negotiated and definitized.[14] Specifically, the modification to the Northrop Grumman contract, which accounts for approximately 40 percent of the total project cost and spans much of the work on the spacecraft and OTE, remains undefinitized more than a year after the project was rebaselined. Once the project completes negotiations for the contract modification and all schedule dates are set, the project can then have a measurable integrated master schedule. Project officials stated that the negotiation process and updating of associated schedules are planned to be complete in January 2013 for the Northrop Grumman contract modification—a year after submission of the latest update to its proposal for the replan. The project also reported that multiple audits of the proposals submitted by Northrop Grumman and its subcontractor by the Defense Contract Audit Agency have delayed definitization. Negotiations for the modification to NASA's contract with the Space Telescope Science Institute to incorporate the October 2018

[13] GAO-12-120G.

[14] An integrated master schedule constitutes a program schedule that includes the entire required scope of effort, including the effort necessary from all government, contractor, and other key parties for a program's successful execution from start to finish. As a key focal point for management, the integrated master schedule documents and integrates the planned work, the resources necessary to accomplish that work, and the associated budget. It also consists of logically related activities whose forecasted dates are automatically recalculated when activities change allowing for management to respond to the consequences of these changes.

launch readiness date are not scheduled to be complete until spring 2013.

Once all the contracts have been definitized and the project's integrated master schedule is baselined, we plan to conduct a comprehensive best practices assessment of the reliability of the project's schedule estimates.

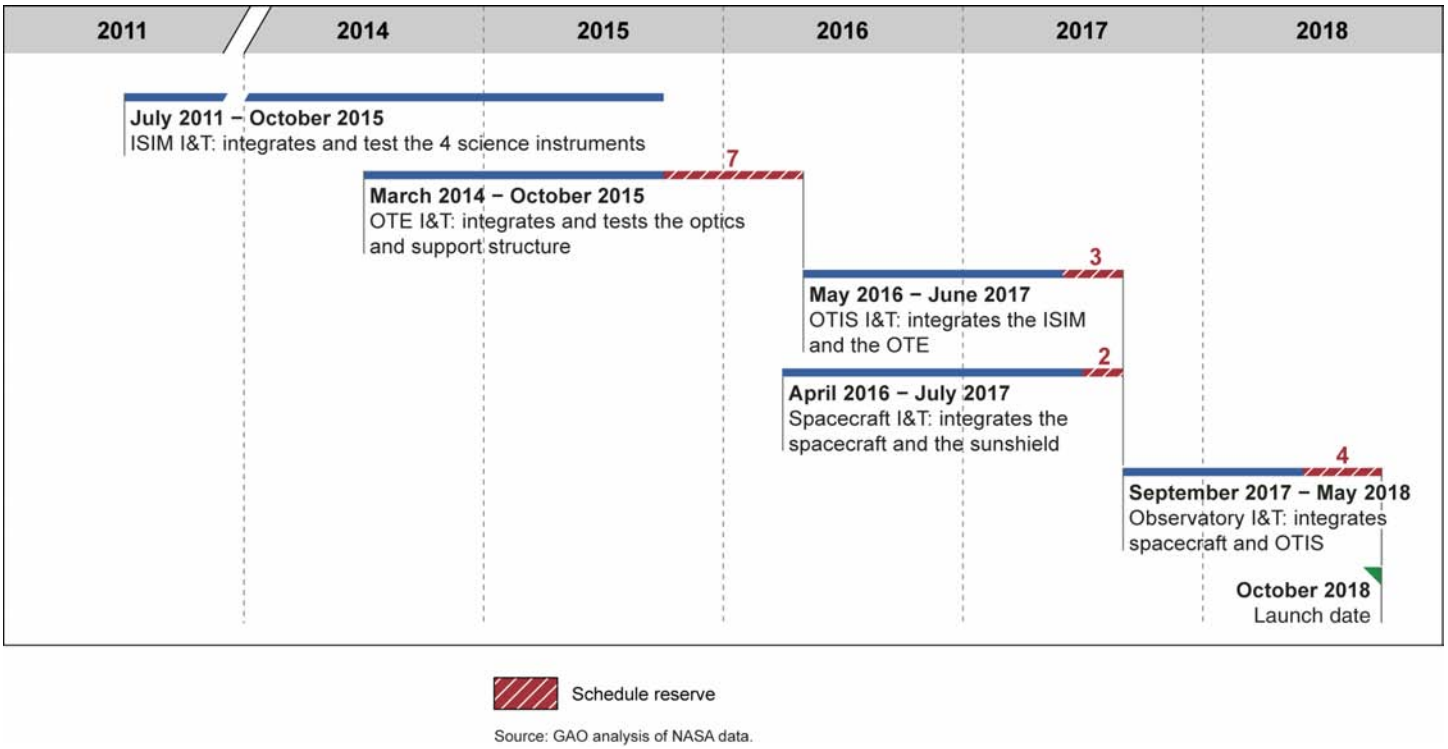
## Technically Challenging JWST Project Lacks the Schedule Reserve Flexibility and Commensurate Oversight of Integration and Test Efforts

Project officials report that the JWST schedule has 14 months of reserve, which meets Goddard guidance for schedule reserve; however, only 7 of the 14 months are likely to be available for the last three of JWST's five complex integration and test efforts. GAO's prior work shows that it is during integration and test where problems are commonly found and schedules tend to slip. Given that JWST has a challenging integration and test schedule, this could particularly be the case. The project has made some significant progress in the past year, notably successfully completing development of the 18 primary mirror segments—considered JWST's top technical risk. Nevertheless, ongoing challenges are indicative of the kinds of issues that can require a significant amount of effort to address. For example, instrument challenges have delayed the first integration and test effort. In addition, key long-term risks on subsystems with a significant amount of work remaining will not be retired until 2016. Currently, NASA's plan for project oversight calls for one independent system integration review about 13 months before launch. While this is consistent with what NASA requires for its projects, this approach may not be sufficient for a project as complex as JWST. As a result, the current plan may be inadequate to ensure key technical and management issues are identified early enough to be addressed within the current integration and test phase schedule.

### Test and Integration Schedule Lacks Schedule Reserve Late in the Process

JWST has a complex and lengthy integration and test phase, which includes five major integration and test efforts—ISIM, OTE, OTIS, spacecraft, and observatory. See figure 4 for the project reported dates for the major integration and test efforts and the schedule reserve allocated for each effort.

**Figure 4: Project Integration and Test Time Line**




Source: GAO analysis of NASA data.

Overall, project officials report that the critical path schedule has 14 months of reserve with 7 months after the ISIM and OTE integration and test efforts. If these efforts are delayed beyond those 7 months, they will impinge on the schedule for the remaining three integration and test efforts. Project officials stated that the baseline plan is for the OTIS integration and test effort to not begin earlier than May 2016. These officials reported it is likely that all of the 7 months of schedule reserve held by the OTE subsystem will be utilized during its integration and test prior to delivery to OTIS and that the OTE effort is on the critical path for the project. Therefore, the remaining integration and test efforts—OTIS, Spacecraft, and Observatory—will likely have at most 7 months divided among them to use if issues are found during integration and test.

In addition to not likely being able to conserve any of the unused first 7 months of schedule reserve, the project has limited time allocated to the final three integration and test efforts, with between 2 to 4 months for each. This time could be used easily by the project if an issue were to arise during integration and test. An example of this is seen in the OTIS

integration and test schedule, which currently has 3 months of schedule reserve. The final event in the OTIS integration and test effort is a lengthy cryo-vacuum test—the first time that the optics integrated with the instruments will be tested at operational temperatures near absolute zero (less than -400 degrees Fahrenheit)—that takes approximately 3 months, due to the requirements of the test. If an issue were to arise during this test that requires shutting the test down and working on the hardware, the chamber would have to be slowly warmed to a temperature safe for removal of the hardware from the chamber, work would be performed, and the 3-month test process would need to begin again. This could easily exhaust the available schedule reserve. Prior GAO work shows that it is during integration and test when problems are commonly found, and schedules tend to slip. A project official confirmed that this is the case because during integration and test the process is more sequential and there is less flexibility to move work around if problems are found. A NASA Inspector General report on the Mars Science Laboratory, another complex and high-cost mission, found that historically the probability that schedule-impacting problems will arise is commensurate with the complexity of the project.[15] JWST is one of NASA's most technologically complex projects to date.

## Despite Overcoming Several Technical Challenges, JWST Has a Significant Amount of Work with Complex Technical Challenges Remaining

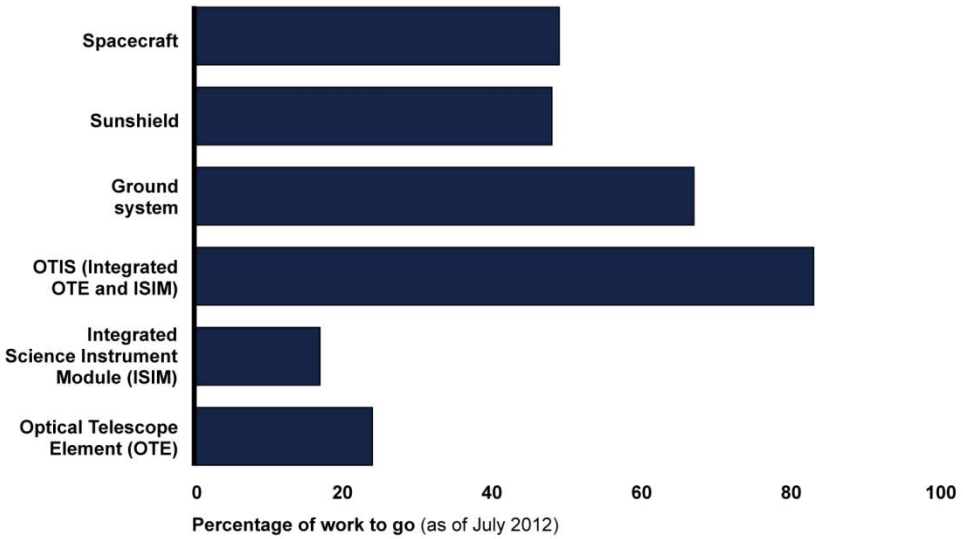
The project has made significant progress overcoming several technical challenges over the last year. In December 2011, for example, the project completed development of the 18 segments of the primary mirror—the project's primary technology risk—approximately 6 weeks ahead of schedule. In addition, project officials stated that during the last year they were also able to accelerate other optics-related work, which added one month of funded reserve to the schedule, bringing the total to 14 months. Finally, the project successfully addressed an increase in the estimated amount of heat on the instruments, which otherwise could have pushed observatory temperatures close to where the optics would not function correctly.

Although technical challenges are being overcome, the project will likely continue to experience additional challenges over the remainder of the project, given the significant portion and complexity of the work

[15]NASA, Office of Inspector General, *NASA's Management of the Mars Science Laboratory Project.* IG-11-019. (Washington, D.C.: June 2011).

remaining. Four of six major subsystems have nearly 50 percent or more of their development work remaining based on its current budget information, although the dollar amounts associated with the work vary. See figure 5.

**Figure 5: Percentage of Budgeted Development Work Remaining for Major Subsystems**




Source: GAO analysis of NASA budget data.

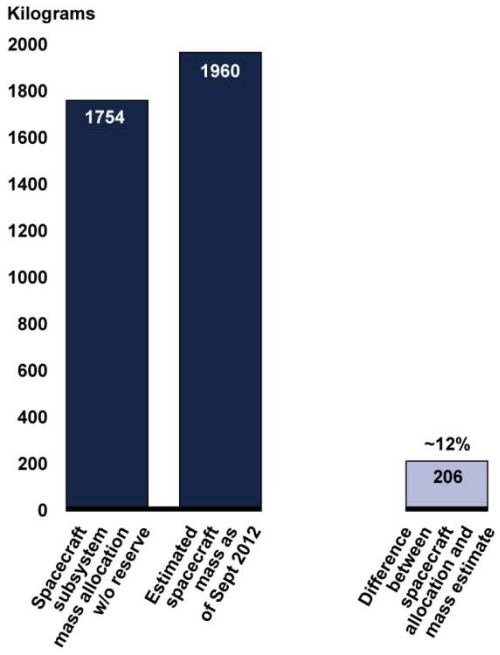
Currently, the project is experiencing several technical issues that have required a significant amount of time and effort to address. For example, the spacecraft subsystem, which experienced delays in development prior to the replan, is currently estimated to be heavier than its mass limit.[16] Spacecraft development has lagged behind other subsystems because it was viewed as a lower risk part of the project and was therefore not allocated funding when budgets were limited prior to the replan. In March 2010, the project passed its mission critical design review, which evaluated the project design and its ability to meet mission requirements and indicated that the design was ready for fabrication phase; however,

[16] Mass is a measurement of how much matter is in an object. It is related to an object's weight and is mathematically equal to mass multiplied by acceleration due to gravity. The project uses mass for JWST because when it goes into space, its weight changes with gravity, but its mass stays the same.

the spacecraft was not included in this review due to its delayed development. Under the initial replan, which had constrained funding in fiscal years 2011 and 2012, the spacecraft critical design review was scheduled for June 2014; however, due to additional funding in the final agency-approved replan, the project was able to accelerate work and this review is now planned for December 2013.

Project officials have been concerned with the mass of JWST since its inception because of the telescope size and the limits of available launch vehicles. Accordingly, mass limits have been allocated for each subsystem, including the spacecraft. Project officials stated that they expected to encounter mass growth on the spacecraft, but that the magnitude of the mass growth on the spacecraft was unexpected. As shown in figure 6, the current spacecraft projected mass exceeds its mass allocation.

**Figure 6: Current Mass Estimate for Spacecraft Subsystem**




Source: GAO analysis of NASA data.

Primary drivers of the mass growth on the spacecraft are increases in the estimated weight of the wiring harnesses, which distribute power and electric signals between different parts of the observatory, the solar array, and other structures that make up the spacecraft. The burden to find

ways to reduce mass has been primarily placed with the spacecraft because it was assessed by the project to have the least technical risk and because it is the least mature subsystem and can more easily accommodate design changes. Over 100 kilograms, or 220 pounds, of mass savings options are being evaluated by the project and Northrop Grumman, which is developing the spacecraft. Potential mass solutions have been identified by Northrop Grumman and the project; however, cost and risk vary with each solution and the project is still evaluating the trade-offs of the various solutions. Project officials stated that final decisions for all tradeoffs will need to occur before spacecraft critical design review in December 2013.

The ISIM subsystem is experiencing technology and engineering challenges that resulted in the use of 18 of ISIM's 26 months of schedule reserve. The schedule for the instruments needed for ISIM continues to slip, which could result in use of more schedule reserve. Based on the replan, all four instruments were to be delivered by September 2012; however, only two instruments were delivered by that time and those still have issues that must be addressed. The remaining two instruments are currently scheduled to be delivered at least 11 months late. See table 1 below for the instrument specific issues.

**Table 1: Issues with JWST Science Instruments Included in ISIM**

| Instrument | Instrument specific issues |
|---|---|
| **MIRI** | MIRI was delivered in May 2012, 1 month later than the replan date, which did not impact the ISIM integration and test schedule. However, the instrument team is still working to address an instrument sensitivity issue. The instrument team is conducting data analysis to determine a root cause for why the instrument is less sensitive than required. A formal report on the root cause and recommended corrective action is expected in November 2012. NASA officials report that preliminary findings indicate that hardware changes will not be necessary. |
| **NIRSpec** | NIRSpec is currently planned for delivery in August 2013, a delay of 11 months from the replan date as a result of several technical issues. First, in July 2011, three cracks were found in the part that holds the optics components for the instrument. A failure review board was held in January 2012. ESA, which is building the instrument, will need to reassemble the instrument using the flight spare part. This part cannot be rebuilt in time to include the instrument in the first of three cryo-vacuum tests of ISIM. The project team adjusted the integration and test schedule to be able to accept delivery of NIRSpec in February 2013. However, additional issues during testing, including failure of the microshutters to close and slower than planned progress on the reintegration by the ESA contractor, have further delayed NIRSpec until August 2013. The microshutters were provided to ESA by Goddard Space Flight Center and enable the instrument to study 100 targets simultaneously. To mitigate schedule risk, the project is studying an option to build new microshutters that will replace the current ones, if necessary. Delivery of NIRSpec after August 2013 may threaten ISIM's critical path schedule. |

| Instrument | Instrument specific issues |
|---|---|
| **FGS/NIRISS** | FGS/NIRISS was delivered as planned in July 2012; however, it was delivered with a known gear motor issue that could result in the early loss of NIRISS in space. In July 2012, the Canadian Space Agency (CSA), which built the instrument, began to redesign the gear motors and they are being rebuilt. Around the time of the replan, CSA had to redesign its instrument because the original design was not meeting performance requirements. Part of instrument design was simplified, which resulted in some loss of expected science performance; however, NIRISS science is not required for JWST mission success. |
| **NIRCam** | NIRCam is currently planned for delivery in August 2013, a delay of 11 months from the replan date as a result of technical and workmanship issues. The project determined the need to electrically ground a mirror on the instrument and the team is reviewing several potential options to address this issue. Workmanship issues, such as poor soldering quality of the wires in the instrument controls electronic box, resulted in the need for corrective actions. The project has decided to run the first ISIM cryo-vacuum test without NIRCam. |

Source: GAO analysis of NASA information.

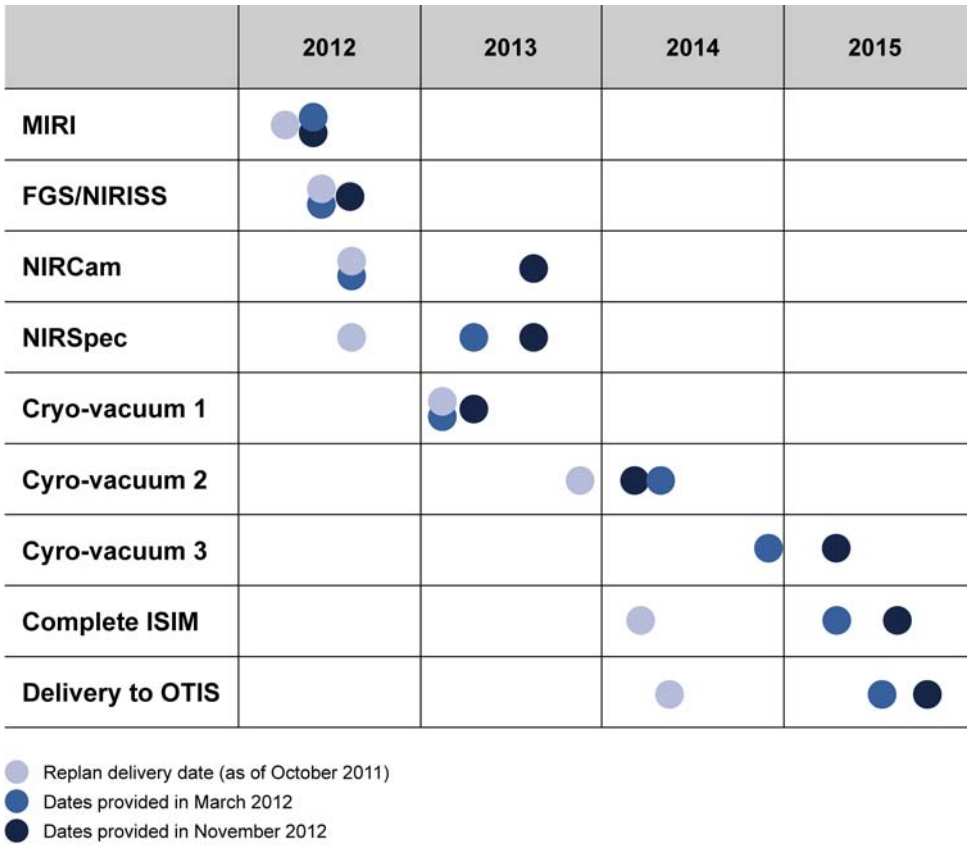
In addition to the instrument delays, two other technical challenges associated with ISIM are: (1) the detectors used by three of the four instruments to capture infrared light in space are degrading and may need to be replaced, resulting in the addition of another round of cryo-vacuum testing—in which a test chamber is used to simulate the near absolute zero temperatures in space, and (2) issues with the development of the cryo-cooler system that removes heat and cools MIRI. In December 2010 the project became aware that the detectors in three of the instruments were degrading.[17] As a result, approximately $42 million and 15 months of schedule reserve to replace the detectors were included in the replan. These additions covered the cost of manufacturing the detectors; fabrication, assembly, and test of new focal plane assemblies; changing the detectors on three instruments, and the addition of a third ISIM cryo-vacuum test. The manufacturing process for new detectors takes approximately 30 months, which means that they cannot be delivered until after the second round of ISIM cryo-vacuum testing in 2014. As a result, $2 million of the $42 million in the replan was used to add a third round of cryo-vacuum testing for ISIM. The third test will validate the performance requirement of the ISIM and is the only time the instruments are tested with the flight detectors. Changing the detectors requires disassembling the instruments from ISIM, a process that will risk damage to the structure and instruments. Project officials stated that they will continue to monitor the degradation rate of the current detectors because if the degradation rate is low, they may not replace the detectors.

[17]NIRCam, NIRSpec, and FGS/NIRISS use detectors fabricated by the same vendor; whereas MIRI uses different detectors that do not need to be replaced.

Development issues with a part of the cryo-cooler needed for MIRI have delayed its delivery to ISIM. In 2010, project officials realized that an essential valve in the cryo-cooler was leaking at rates that exceeded requirements. Following the results of a failure review board, the contractor manufactured a newly designed valve, but it also did not meet leak rate requirements. Project officials stated that a new valve design will not be manufactured in time for use in the first ISIM cryo-vacuum test. The project is concurrently developing three alternatives and authorized manufacturing for one of the alternatives in October 2012. Project officials stated that the MIRI cryo-cooler is particularly complex because it spans approximately 10 meters—or approximately 33 feet—through the entire JWST observatory. These issues combined required the use of 18 months of schedule reserve, which reduced ISIM's schedule reserve from the 26 months established in the replan to 8 months before it is needed for integration with the OTIS subsystem.

These types of issues are not uncommon among NASA programs as technical issues tend to arise when disparate parts are integrated and tested together for the first time. Given the complexity and cutting edge technology developed and used on JWST, it is expected that these kinds of issues will continue to materialize as the program moves through its complex integration and test program. Figure 7 shows the delay of instrument deliveries as well as changes to the ISIM integration and test and final delivery dates over the last year.

**Figure 7: Changes in ISIM Schedule Since the Project Replan**




Source: GAO analysis of NASA data.

Until the project is able to overcome the major issues with the instruments and other parts of the ISIM, it is likely that the schedule would continue to slip and may begin to affect the overall project schedule. ISIM still has 8 months of schedule reserve before the slipping of its schedule would affect the schedule for the remainder of the project. The instrument, detector, and cryo-cooler issues have all contributed to the delay in the ISIM integration and test schedule and the reduction of objectives that can be achieved in the first two rounds of cryo-vacuum testing. The first round of testing will not include two instruments, a final design of the cryo-cooler hardware, or new detectors. As a result project officials will only be able to gather risk reduction information on the FGS/NIRISS, MIRI, test procedures, and test support equipment from the first cryo-vacuum test.

The project also has several known long term risks and challenges remaining. For example, risks related to OTIS, the sunshield, and the

ground system subsystems are not scheduled to be addressed until late in project development. As of October 2012, seven of the top 10 project risks were related to the long-term risks associated with the OTIS and sunshield, most of which will not be resolved until 2016 or later. For example, several risks relating to OTE are not scheduled to be closed until the OTIS testing in the chamber at Johnson Space Center in February 2017. Project officials are adding risk mitigation through early and additional testing, where possible, to these subsystems. Prior to the replan, the ground system software was at high risk for not being completed before launch and many tasks were planned for completion after launch. Space Telescope Science Institute officials stated that the replan allows them to plan for completion of their work before launch on a more realistic time schedule, which decreases schedule and operational risk. A continuing challenge on the ground system is that some development and testing is dependent on the final design of subsystems such as the instruments, which continue to slip delivery dates.

## Independent and Management Oversight during Test and Integration May Not Be Commensurate with JWST Test and Integration Complexity

The project plans to hold independent and management reviews required for all projects during the integration and test phase, but this phase for JWST is particularly complex. JWST has five major integration and test efforts that span 7 years and only one independent mission-level technical review—the system integration review. The system integration review evaluates the readiness of the project and associated supporting infrastructure to begin system assembly, integration, and test, and evaluates whether the remaining project development can be completed within available resources. For JWST, this review is scheduled in September 2017, only 13 months prior to launch. Projects we reviewed that had recently launched, however, held their system integration review on average approximately 22 months prior to launch. The project has an internal review with participation from standing review board members planned before the beginning of OTIS integration and test activities begin, and it will be subject to independent lower level reviews conducted by the Goddard Systems Review Office of the integration and test process. In addition, key decision point D (KDP-D)—when the senior agency decision authority would approve the project to proceed into the system integration and test phase—is scheduled for December 2017, 3 months after the commencement of the final major integration and test activity. According to NASA policy, this review should be held prior to the start of the system

integration and test phase of the project.[18] Project budget information shows that over 90 percent of expected integration and test funding will be spent on four major integration and test activities prior to the scheduled mission-level system integration review and KDP-D approval by NASA senior management. As a result, the current plan may be inadequate to ensure that key technical and management issues are identified early enough to be addressed within the current integration and test phase schedule.

## JWST Project Has Taken Steps to Enhance Communications with and Oversight of Its Contractors

The JWST project has taken steps to improve communications and oversight of its contractors as part of the replanning activities. For example, based on recommendations from the ICRP, the project has instituted meetings at various levels throughout NASA and its contractors and subcontractors. In addition, the project has added personnel at contractor facilities, which has allowed for more direct interaction and quicker resolution of issues. The project also assumed responsibility of the mission-level systems engineering function from Northrop Grumman, a move that shifts the authority to make trades or decisions to NASA. An independent NASA review of the project conducted in May 2012 found, however, that agencywide reductions in travel budgets have put the effectiveness of the JWST project's oversight plans in jeopardy. While the project received partial relief from travel budget reductions in fiscal year 2012, project officials are concerned that the current level of oversight will not be sustained if similar cuts in travel funding occur in future years as anticipated. The project is also taking steps to enhance its oversight of project risks by implementing a new risk management system. The new project manager found that the previous system lacked rigor and was relatively ineffective for managing project risks, especially for a project as complex as JWST. The new system should allow for better tracking of risks than did the previous system. While these enhancements to the oversight of the project are steps in the right direction, it will take time to assess their effectiveness.

[18]NPR 7120.5E, table 2-5 and appendix A (Aug. 14, 2012).

## NASA Responded to Recent Independent Review Panel Report with Increased Communication and Oversight

Based on recommendations in the ICRP report, NASA has taken action to enhance oversight and communications. See table 2 for the ICRP recommendations and actions taken by NASA in response.

**Table 2: ICRP Recommendations Concerning Oversight and Communications and the Actions Taken by NASA**

| ICRP recommendation | Action taken |
|---|---|
| Move the JWST management and accountability from the Astrophysics Division to a new organizational entity at NASA headquarters that has responsibility only for the management and execution of JWST. | Completed: The management of JWST at Headquarters has been reorganized. JWST is now a stand-alone program reporting to the NASA Associate Administrator for programmatic oversight and to the Associate Administrator for the Science Mission Directorate for technical and analysis support. A similar approach was taken in the past with both the Hubble Space Telescope and the Mars Exploration Program. |
| Assign management and execution responsibility for the JWST Project to the Goddard Center Director, with accountability to the Science Mission Directorate Associate Administrator at NASA headquarters. | Completed: NASA has reorganized the JWST project at Goddard to report directly to the Center Director, who is responsible for the management and execution of the JWST Project and accountable to the NASA Administrator. |
| Assign at least one senior Goddard project person to be resident at Northrop Grumman throughout the Project. | In progress: In August 2012, the Deputy Observatory Manager began spending at least half time at the Northrop Grumman facility, with a permanent move scheduled in early 2013. |
| Improve communications between the JWST Project and both Goddard management and NASA headquarters Science Mission Directorate. | Completed: The JWST project office provides weekly updates of risks and new issues to the Goddard Center Director. In addition, the Project Manager at Goddard has daily interaction with the Program Manager at NASA HQ. |
| Conduct monthly or bi-monthly JWST Project Executive meetings, attended by the NASA Associate Administrator and the President of Northrop Grumman Aerospace Systems. | Completed: Meetings were first held in December 2010 between the NASA Associate Administrator, the new JWST Program Director, and the Goddard Center Director and senior management of the prime contractor. Since that time, senior level management reviews have occurred on a quarterly basis and are open to subcontractors as well. Topics at these meeting have included issues such as the spacecraft mass problems, instrument delivery delays, and the process to find alternative solutions for the MIRI cryo-cooler valve problem. |
| Strengthen the role and the independent voice of the science team in the Project. | Completed: The project added a Deputy Senior Project Scientist/Technical position to the project science team. This individual:<br>• is responsible for day-to-day interactions with senior project management on all aspects of the mission; scientific, technical, budgetary, and schedule.<br>• meets regularly with other members of the project science team to ensure better communication with other functions in the project.<br>• assists the Senior Project Scientist to facilitate better integration of the science activities with the hardware development activities and enable closer coordination and understanding of technical drivers to science performance so fully informed decisions can be made. |

Source: GAO analysis of NASA data.

NASA has taken steps to increase communication between the project and its contractors and subcontractors in an effort to enhance oversight. According to project officials, the increased communication has allowed them to better identify and manage project risks by having more visibility into contractors' activities. The project reports that a great deal of communication existed across the project prior to the ICPR and replan; however, improvements have been made. For example, monthly meetings between project officials at Goddard and all of the contractors have continued on a regular basis and include half-day sessions devoted to business discussions. The project reports that these meetings have benefits over other forms of communication. For example, it was through dialogue with several technical leads at Northrop Grumman during detailed reviews of analytical models that the project identified that the mass issue on the spacecraft was likely to occur.

In addition, the project has increased its presence at contractor facilities as necessary to provide assistance with issues. For example, the project has had two engineers working on a recurring basis at Lockheed Martin to assist in solving problems with the NIRCam instrument. The ISIM manager said that these engineers have insight into Lockheed Martin's work and are having a positive effect as they offer technical help and are involved in devising the solutions to issues. He added that that these engineers have authority to make decisions on routine issues to allow the work flow to continue, but decisions that are more complex or require a commitment of funds are communicated to project management for disposition. The project reports that the Jet Propulsion Laboratory, responsible for NASA contribution to the MIRI instrument and its associated cryo-cooler, has an in-house representative in the responsible Northrop Grumman division to monitor the work being performed on the cryo-cooler.

The JWST project also assumed full responsibility for the mission system engineering functions from Northrop Grumman in March 2011. NASA and Northrop Grumman officials both said that NASA is better suited to perform these tasks. Project officials stated the systems engineering requires the ability to make trades and decisions across the entire observatory, and because Northrop Grumman is only responsible for portions of the observatory, it did not have the authority to make trades or decisions for areas outside of its control. Although responsibility for the overall mission systems engineering function was removed from Northrop Grumman, it retains system engineering responsibility for work still under its contract, such as development of the spacecraft and sunshield. The ICRP noted that a highly capable, experienced systems engineering

group is fundamental to project success and appropriate to ensure accountability especially for a project of JWST's complexity and visibility.

While these enhancements to the oversight of the project are steps in the right direction, it will take time to assess their effectiveness. In addition, sustainment of these efforts on the part of the project will be important. Project and contractor officials we spoke with believe that the increased communication has had a positive effect on the relationships between them. We will continue to monitor the interaction between the project and its contractors and its frequency in future reviews to identify whether the changes have had the desired results.

## Travel Budget Reductions May Hamper Planned Oversight Activities

The JWST project reported that its travel budget was reduced by approximately $200,000 from the $1.2 million planned in fiscal year 2012 as a result of NASA's implementation of an Executive Order to promote more efficient spending.[19] According to project officials, the changes in oversight necessitated by a reduction in travel funds represent a major shift away from the management paradigm adopted during the replan. Proposed reductions in future fiscal years could significantly reduce the project's travel budget. The project reports that the travel requirements for fiscal years 2013 through 2015 are $1.6 million, $1.7 million, and $1.8 million, respectively. Officials reported that while travel is a small percentage of the project's annual budget, the majority of expected travel—about 87 percent—is for oversight functions put in place as a result of the ICRP recommendations, such as having a permanent on-site presence at Northrop Grumman. These oversight functions include attending and participating in contractor monthly programmatic and technical reviews, technical interface meetings, recurring on-site presence at contractor facilities for quality assurance reviews and inspection of hardware. JWST project officials are concerned that decreased oversight could translate into the project increasing its use of cost and schedule reserves as they will not be conducting planned oversight to better ensure success. A recent NASA Office of Evaluation review concluded that by not having an adequate travel budget, the project is at risk of cost/schedule growth and/or technical risk due to the

[19]Executive Order 13589, *Promoting Efficient Spending*, The White House, November 9, 2011. NASA provided allocations to the Centers based on this order. In turn, Goddard conducted an internal travel prioritization process and center management determined the allocation for JWST and other Goddard projects.

late identification of issues or timely resolution strategies. The project has made adjustments to absorb the reduction in fiscal year 2012 and plans to identify instances of increased cost or schedule risk due to late identification of issues. However, the project does not have a strategy to address anticipated future reductions. Ensuring adequate oversight is particularly important as the project begins its complex and lengthy test and integration phase, where issues will likely surface.

## NASA Headquarters Independent Review of the JWST Program Identified Concerns and Recommends Indicators to Measure Progress

As part of NASA's approach to increase oversight of the project at headquarters, NASA's Office of Evaluation recently conducted an independent review of the JWST project to assess the progress since the September 2011 rebaseline was approved. According to the Director of the Office of Evaluation, the goal of the review was not to reproduce the replan assessment, but rather to assess progress based on cost, schedule, and technical performance of the project and the status of oversight functions within NASA headquarters, the JWST Program Office, and Goddard Space Flight Center. The intended outcome of the review was 1) to obtain a snapshot of performance to determine if the program was progressing in accordance with its plan, and 2) to identify leading indicators for upper management to use when tracking future performance. The review team identified several areas of concern within the program, many of which we have highlighted, and recommended a list of leading indicators that project management should consider tracking.

The Director of the Office of Evaluation said that the project is generally performing the activities and maintaining the schedule set forth in the replan; however, the team identified key areas that should be monitored as the project moves forward. The review team also recommended a set of leading indicators for project management to consider tracking to measure and monitor progress. The Director added that these indicators are for the project to use and would not be specific criteria for use by independent review boards such as the Standing Review Board. These indicators are a positive step to ensure that NASA management has the information necessary to monitor the progress of the JWST project. See table 3 below for the concerns raised by the review team.

**Table 3: NASA Office of Evaluation Review Team Concerns**

| Concern identified | NASA Office of Evaluation Review Team finding |
|---|---|
| Resolving the on-going mass issue.[a] | The technical and programmatic risks involved in possible solutions need to be explicitly understood. |
| Understanding root causes for the NIRSpec Optical Bench cracking issue. | There needs to be a better understanding of the root causes and investigate what would constitute a flyable structure. |
| Monitoring of schedule erosion by the project and recognition of the dynamics of four competing critical paths.[a] | There are several competing critical paths for the JWST program to include development and integration and test of the OTE, ISIM, sunshield, and the spacecraft. |
| Monitoring the stability of the schedule going forward. | The master schedule took 8 months to baseline and stability of the schedule going forward is unknown. The project will need an accurate reporting system at the integrated master schedule level. |
| Ensuring that Northrop Grumman will have an adequate workforce and that skills are available in fiscal year 2013.[a] | The project needs to work with Northrop Grumman to ensure that it has an adequate workforce and skill sets available to accomplish the planned ramp up for fiscal year 2013. |
| Monitoring the increased risk of cost/schedule growth and technical risk. | Without an adequate travel budget to execute the original plan, there is an increased risk of cost or schedule growth and technical risks due to late identification of issues or timely resolution strategies. |

Source: GAO analysis of NASA data.

[a]These issues were also identified as leading indicators the review team recommended that project management should consider tracking.

## Changes Made to Project Risk Management System

The new JWST project manager re-emphasized the importance of the project's risk management system and, in August 2012, a new risk management database was implemented to support the system. The project manager told us that he evaluated the risk management system being utilized by the project when he assumed his position and found it to be ineffective and not robust, especially for a project as complex as JWST. While the basic risk management methodology remains unchanged, the project manager wanted a more regimented system. For example, the project utilizes a hierarchy of risk boards that periodically reviews and provides disposition of all new and existing risks. These risk boards reviewed and assessed new risks and lower level risk board actions and met on an ad hoc basis. The project manager instituted a more regimented system that re-emphasized and revised the weekly project risk board meetings. Lower level risk boards meet a minimum of once a month depending on activity.

The project manager also determined that a new risk management database needed to be put in place that would bring more rigor to the risk management process. The project manager told us that he directed an overhaul of the risk management database to provide more complete information to management on the purpose and history for each risk. The

goal was to improve consistency in how the project determined the potential for a risk to occur and its impact, and provide greater detail on mitigation and better tracking of the status for each risk. For example, the new system puts more emphasis on understanding and capturing the key events in the mitigation plan that are intended to result in a change in likelihood or consequence of a risk. The new system has a provision where the mitigation plan will be entered and updated over time, and the capability to store data such as mitigation steps throughout the life of the risk. In addition, the new system now archives data automatically to provide a traceable history of the risk. The prior data system did not have as robust of an archiving function. Furthermore, the project manager wanted to improve the linkage between the risk database entries and financial records to ensure consistency of the data in the risk database with regard to cost and schedule for risk mitigations with project office financial records. As the changes to the risk management system and database, as well as other changes we identified that were put in place to enhance oversight were just recently implemented, we will continue to monitor their continued use and assess the impact they may be having on the project.

## Conclusions

The JWST project is among the most challenging and high-risk projects NASA has pursued in recent years. It is also one of the most expensive, with a recent major replan resulting in a total cost of $8.8 billion. The reasons for cost and schedule growth were largely recognized by an independent review team to be rooted in ineffective funding, management, communication, and oversight. NASA has invested considerable time and resources replanning the project and instituting management and oversight improvements in order to ensure that it (1) can be executed within its new estimates and (2) has addressed the majority of issues raised in the recent independent review. It appears that communications with contractors and within NASA have improved, that a more robust risk mitigation system is in place, that more is known about what it will take to complete the project and how much it will cost, and that the project is currently meeting the majority of its milestones. Nevertheless, over the course of the next several years, the project will be executing a large amount of work with several extremely complex and challenging integration and test efforts. Because three major test and integration efforts must be completed in the last 2 years of the JWST schedule, it is essential that issues are identified and addressed early enough to be handled within the project's current schedule. While the JWST oversight plan is consistent with NASA's requirements for all project's required reviews, a single independent review scheduled just

over a year before launch may not be sufficient to identify and resolve problems early for a project of this magnitude. A key element of overseeing project progress is monitoring how the project is executing to its cost baseline. To that end, while NASA took some steps that were in line with best practices to develop its revised baseline, some of the deficiencies we found in its process could impact the reliability of the cost estimate and the joint cost and schedule confidence level that was provided to headquarters decision-makers. Without higher-fidelity, regularly updated information related to costs, as well as an oversight regime during later phases of test and integration that is commensurate with the complexity of that effort, NASA risks late identification of technical and cost issues that could delay the launch of JWST and increase project costs beyond established baselines. Also important to oversight for the remainder of the project is the ability of officials to sustain improvements to communication with and oversight of contractors. Anticipated travel restrictions, however, could decrease the project team's ability to sustain these actions. Without a plan to address such reductions in future years, the project could once again become susceptible to communication and oversight problems identified in earlier reviews, which could also have a detrimental impact on continued project performance.

## Recommendations for Executive Action

To ensure that the JWST life-cycle cost estimate conforms to best practices, GAO recommends that the NASA Administrator direct JWST officials to take the following three actions to provide high-fidelity cost information for monitoring project progress:

- improve cost estimate documentation and continually update it to reflect earned value management actual costs and record any reasons for variances,
- conduct a sensitivity analysis on the number of staff working on the program to determine how staff variations affect the cost estimate, and
- perform an updated integrated cost/schedule risk analysis, or joint cost and schedule confidence level analysis, using a schedule that meets best practices and includes enough detail so that risks can be appropriately mapped to activities and costs; historical, analogous data should be used to support the risk analysis.

To ensure that technical risks and challenges are being effectively managed and that sufficient oversight is in place and can be sustained,

GAO recommends that the NASA Administrator direct JWST officials to take the following three actions:

- conduct a separate independent review prior to the beginning of the OTIS and spacecraft integration and test efforts to allow the project's independent standing review board the opportunity to evaluate the readiness of the project to move forward, given the lack of schedule flexibility once these efforts are under way,
- schedule the management review and approval to proceed to integration and test (key decision point D or KDP-D) prior to the start of observatory integration and test effort, and
- devise an effective, long-term plan for project office oversight of its contractors that takes into consideration the anticipated travel budget reductions.

## Agency Comments and Our Evaluation

NASA provided written comments on a draft of this report. These comments are reprinted in appendix IV. NASA also provided technical comments, which were incorporated as appropriate.

In responding to a draft of this report, NASA concurred with three recommendations and partially concurred with three other recommendations and commented on actions in process or planned in response. In some cases, these actions meet the intent and are responsive to issues we raise; however, some of the responses do not fully address the issues we raised in the report.

NASA partially concurred with our recommendation to improve the cost estimate documentation of the JWST project, and to continually update it to reflect earned value management actual costs and record any reasons for variances between planned and actual costs. In response to this recommendation, NASA officials stated that the project currently receives earned value data from some of its contractors and performs monthly analysis of that data to understand the contractors' estimates at completion, and then compares these numbers to similar figures independently assessed by the JWST project. NASA also highlighted its efforts to improve the agency's documentation of the earned value variances and to extend the earned value management analysis to areas where it is not yet implemented, such as ground systems development at the Space Telescope Science Institute. In addition, NASA responded that its annual budget process generates a requirements-driven budget plan consistent with the rebaseline. NASA stated that this information is updated in several different documents that are provided to management

and it does not plan to revise its JCL documentation developed during the replan. Despite these steps, we could not independently confirm that they were leading to an updated cost estimate, which is the basis of our recommendation. If the estimate is not updated, it will be difficult to analyze changes in project costs and collecting cost and technical data to support future estimates will be hindered. Furthermore, if not properly updated on a regular basis, the cost estimate cannot provide decision makers with accurate information for assessing alternative decisions. Without a documented comparison between the current estimate (updated with actual costs) and the old estimate, the cost estimator cannot determine the level of variance between the two estimates and cannot see how the project is changing over time. Therefore, we continue to believe NASA will be well served by following best practices and updating its cost estimate with current information and documenting reasons for any variances. We encourage the project to improve the cost estimate documentation and record any reasons for variances between planned and actual costs and we intend to review the documentation as a part of our ongoing review of the project.

NASA officials partially concurred with our recommendation that the project conduct a sensitivity analysis on the number of staff working on the project to determine how staff variations affect the cost estimate. In its response, the agency stated that it believes it met the intent of this recommendation when staffing levels were determined in the 2011 JWST rebaseline based on programmatic experience from the accomplishment of similar activities. To accommodate the possibility of increased costs based on increased staffing hours, NASA reports that funded schedule reserve was built into the JWST rebaseline, in addition to unallocated future expenses being held at various levels of the organization. NASA believes that these reserves will be sufficient to cover increases for the duration of specific activities that result in increased staffing cost, and that an additional workforce sensitivity analysis is not warranted. NASA added that the joint cost and schedule confidence level analysis performed provided a de facto workforce sensitivity analysis and does not plan any further action. A joint cost and schedule confidence level analysis, however, is not the same as a sensitivity analysis wherein the sources of the workforce variation should be well documented and traceable. While we appreciate the steps NASA took to account for workforce variation, the JWST cost model does not show how staff levels increasing or decreasing over time affects cost. Furthermore, best practices call for a risk analysis to be conducted in conjunction with a sensitivity analysis, not to be a substitute for it. As a best practice, a sensitivity analysis should be included in all cost estimates because it examines the effects of changing

assumptions and ground rules. Since uncertainty cannot be avoided, it is necessary to identify the cost elements that represent the most risk and, if possible, cost estimators should quantify the risk. Without performing a sensitivity analysis that reveals how the cost estimate is affected by a change in a single assumption, such as workforce size, the cost estimator will not fully understand which variable most affects the cost estimate. Therefore, we continue to believe that NASA should conduct a sensitivity analysis for the JWST project, given the large number of staff working on the program, to determine how staff variations positively or negatively affect the cost estimate rather than relying on schedule reserve and unallocated future expenses to offset any shortfall.

NASA concurred with our recommendation to perform an updated integrated cost and schedule risk analysis using a schedule that meets best practices and includes enough detail so that risks can be appropriately mapped to activities and costs. In response to this recommendation, NASA stated that the agency is already using tools and a method to conduct programmatic assessments of projects after the baseline was established using the JCL methodology. While these may be good tools, the key point is the need to address shortcomings of the schedule that supports the baseline itself. For example, the lack of detail in the summary schedule used for the joint cost and schedule risk analysis prevented us from sufficiently understanding how risks were incorporated; therefore, we question the results of that analysis. Since the JCL was a key input to the decision process of approving the project's new cost and schedule baseline estimates, we maintain that the JWST project should perform an updated JCL analysis using a schedule with sufficient detail to map risks to activities and costs. Doing so could help increase the reliability of the cost estimate and the confidence level of the JCL. Furthermore, risk management is a continuous process that constantly monitors a project's health. Given that JWST is many years from launch and the risks that the project faces are likely to change, a risk analysis should be conducted periodically throughout the life of the project.

NASA concurred with our recommendation to conduct a separate independent review prior to the beginning of the OTIS and spacecraft integration and test efforts. In response to this recommendation, NASA stated that it will request members of the independent JWST Standing Review Board participate in OTIS Pre-Environmental Review scheduled prior to the beginning of OTIS environmental testing. A member of the Standing Review Board will co-chair this review and report its findings to the NASA Associate Administrator, which is the practice of all Standing

Review Board reviews. In addition, NASA plans to direct Northrop Grumman, the spacecraft developer, to add members of the Standing Review Board, as well as members of the Goddard Independent Review Team, to the spacecraft element integration readiness review and report their findings to the NASA Associate Administrator. We believe these actions meet the intent of our recommendation and will afford an independent evaluation of the readiness of the project to move forward with its major integration and test efforts.

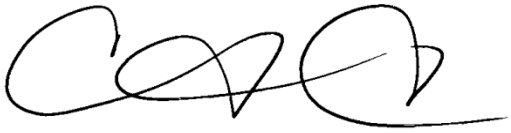
NASA partially concurred with our recommendation to schedule the management review and approval to proceed to integration and test (KDP-D) prior to the start of the observatory integration and test effort. In response to this recommendation, NASA stated that it will reduce the 3-month gap between the scheduled system integration review and the KDP-D review, which it believes will provide NASA management and the NASA Associate Administrator with the full independent assessment earlier than currently planned. While we agree that this change will move the review earlier than previously planned, based on its response, NASA still plans to hold the review after the observatory integration and test is already underway. Holding this review after the observatory integration and test effort is already underway does not meet agency policy and will lessen the impact of the review as it may be inadequate to ensure key technical and management issues are identified early enough to be addressed. KDP-D is the point in which management approval is given to transition to the test and integration phase. We reiterate our recommendation that NASA should hold this important key decision point prior to the beginning of this last major integration and test effort, as required by agency policy.

NASA concurred with our recommendation to devise an effective, long-term plan for project office oversight of its contractors that takes into consideration the anticipated travel budget reductions. In response to this recommendation, NASA stated that it will develop a plan based on fiscal year 2013 travel allocations and will take into consideration anticipated travel budget reductions. In addition, NASA stated that the plan will enable the project to maintain oversight of JWST contractors and their ability to meet performance and delivery deadlines and work closely with the international partners. We believe such a plan will be critical to ensuring adequate oversight, which is particularly important as the project enters into the complex integration and test efforts where issues will likely surface. In addition, we agree with the concerns of project officials that the current efforts to increase communication and oversight may not be sustained if reductions to future travel budgets occur as anticipated. We

encourage the project to complete this plan in a timely manner and intend to review it as a part of our ongoing assessment of the project's oversight efforts.

We will send copies of the report to NASA's Administrator and interested congressional committees. We will also make copies available to others upon request. In addition, the report will be available at no charge on GAO's web-site at http://www.gao.gov.

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



Cristina T. Chaplain
Director
Acquisition and Sourcing Management

*List of Committees*

The Honorable Barbara A. Mikulski
Chairwoman
The Honorable Kay Bailey Hutchison
Ranking Member
Subcommittee on Commerce, Justice, Science, and Related Agencies
Committee on Appropriations
United States Senate

The Honorable Frank R. Wolf
Chairman
The Honorable Chaka Fattah
Ranking Member
Subcommittee on Commerce, Justice, Science, and Related Agencies
Committee on Appropriations
House of Representatives

The Honorable Ralph M. Hall
Chairman
The Honorable Eddie Bernice Johnson
Ranking Member
Committee on Science, Space, and Technology
House of Representatives

# Appendix I: Objectives, Scope, and Methodology

Our objectives were to assess (1) the extent to which NASA's revised cost and schedule estimates are reliable based on GAO best practices, (2) the major risks and technological challenges the James Webb Space Telescope (JWST) project faces, and (3) the extent to which the National Aeronautics and Space Administration (NASA) has improved the oversight of the JWST project. In assessing the project's cost and schedule estimates, we performed various checks to determine that the provided data were reliable enough for our purposes. Where we discovered discrepancies, we clarified the data accordingly. Where applicable, we confirmed the accuracy of NASA-generated data with multiple sources within NASA.

To assess the current life cycle cost estimate of the JWST project, we used the GAO cost guide to evaluate the estimating methodologies, assumptions, and results to determine whether the cost estimate was comprehensive, accurate, well-documented, and credible.[1] We developed standardized data collection instruments to request relevant cost and schedule documentation and questionnaires for project officials to complete. Through the data collection instruments and questionnaires, we gathered basic information pertaining to the project's cost and schedule estimation process. We examined documents from the JWST replan efforts pertaining to the revised cost estimate and the joint cost and schedule confidence level (JCL) analysis, including detailed spreadsheets that contained cost, schedule and project risk information. Project documents we reviewed included basis of estimates for the replan from contractors and the project office, contractor engineering change proposals, the JWST program plan and mission requirements, as well as the NASA cost estimating handbook.[2] To assess how management and independent review teams were involved in the cost estimate process, we also reviewed the project's monthly status presentations to Goddard management, Standing Review Board reports concerning the project's revised baseline estimates, cost estimates conducted by NASA's Independent Program Assessment Office, and the Agency Program Management Council's decision memo for the rebaselined estimate and JCL analysis. We supplemented our analysis by interviewing officials from

[1]GAO-09-3SP. For the cost guide, GAO cost experts assessed measures consistently applied by cost-estimating organizations throughout the federal government and industry and considered best-practices for the development of reliable cost-estimates.

[2]NASA, *2008 NASA Cost Estimating Handbook, (2008).*

Northrop Grumman, the Space Telescope Science Institute, and the JWST program and project offices. After reviewing cost estimate documentation submitted by NASA and conducting numerous interviews with relevant sources within the project office, we calculated the assessment rating of each criteria within the four characteristics by assigning each individual assessment rating: Not Met = 1, Minimally Met = 2, Partially Met = 3, Substantially Met = 4, and Met = 5. We then took the average of the individual assessment ratings for the criteria to determine the overall rating for each of the four characteristics. The resulting average becomes the "Overall Assessment" as follows: Not Met = 1.0 to 1.4, Minimally Met = 1.5 to 2.4, Partially Met = 2.5 to 3.4, Substantially Met = 3.5 to 4.4, and Met = 4.5 to 5.0. We discussed the results of our assessments with officials within the program office at NASA headquarters and the project office at Goddard Space Flight Center.

We supplemented the assessment of the revised 2011 cost estimate with an assessment of the summary schedule used for the JCL, which was a part of the project's cost estimation process, and followed criteria laid out in the GAO schedule guide.[3] These practices address whether the schedule (1) captured all activities; (2) sequenced all activities—that is, listed in the order in which they are to be carried out; (3) assigned resources to all activities; (4) established the duration of all activities; (5) integrated schedule activities horizontally and vertically, which identifies whether products and outcomes associated with other sequenced activities are arranged in the right order, and that varying levels of activities and supporting subactivities are also aligned properly; (6) established for all activities, the critical path, which is the longest continuous sequence of activities that is necessary to examine the effects of activities slipping in the schedule; (7) identified between activities float, which is the amount of time by which a predecessor activity can slip before the delay affects the program's estimated finish date; (8) identified a level of confidence using a schedule risk analysis; and (9) was updated using logic and durations to determine dates. We also reviewed the inputs to the JCL model, the document outlining the methodology of the analysis that accompanied the electronic files, and interviewed cognizant project officials to discuss their use of the summary schedule.

[3]GAO-12-120G.

Because the project's detailed integrated master schedule has not been finalized because of ongoing negotiations and contract modifications, we did not conduct a complete schedule analysis using the GAO schedule assessment guide. We plan to perform this assessment in a subsequent review of the JWST project.

To assess the major short- and long-term risks and technological challenges facing the project, we reviewed the project's risk list, monthly status reviews, and other documentation provided by projects and contractor officials. This information covered the risks, mitigation plans, and timelines for addressing risk and technological challenges. We also interviewed project officials for each major observatory subsystems to clarify information and to obtain additional information on risks and technological challenges. Further, we interviewed officials from the Jet Propulsion Laboratory, Northrop Grumman Aerospace Systems, Lockheed Martin Advanced Technology Company, Teledyne Imaging Sensors, the University of Arizona, and the Space Telescope Science Institute concerning risks and challenges on the subsystems, instruments, or components they were developing. We reviewed GAO's prior work on NASA Large Scale Acquisitions, NASA Office of Inspector General reports, and NASA's Space Flight Program and Project Management Requirements and Systems Engineering Processes and Requirements policy documents.[4] We compared NASA's controls as outlined in these agency policies with the project plan to assess the extent to which the JWST's plan followed the intent of the policies with regard to independent oversight and management approval processes.

To assess the extent to which NASA is performing enhanced oversight of the JWST project, we reviewed documentation from the Independent Comprehensive Review Panel and the project to determine actions taken by NASA in response to the panel's recommendations. We interviewed project officials to understand the impact of these changes on the oversight processes for the project and communication between the project and its contractors. We also interviewed officials from the Jet Propulsion Laboratory, Northrop Grumman Aerospace Systems, Lockheed Martin Advanced Technology Company, Teledyne Imaging Sensors, the University of Arizona, and the Space Telescope Science

[4]NPR 7120.5E (Aug. 14, 2012) and NASA Procedural Requirements 7123.1A, *NASA Systems Engineering Processes and Requirements with Change 1*. (Nov.4, 2009).

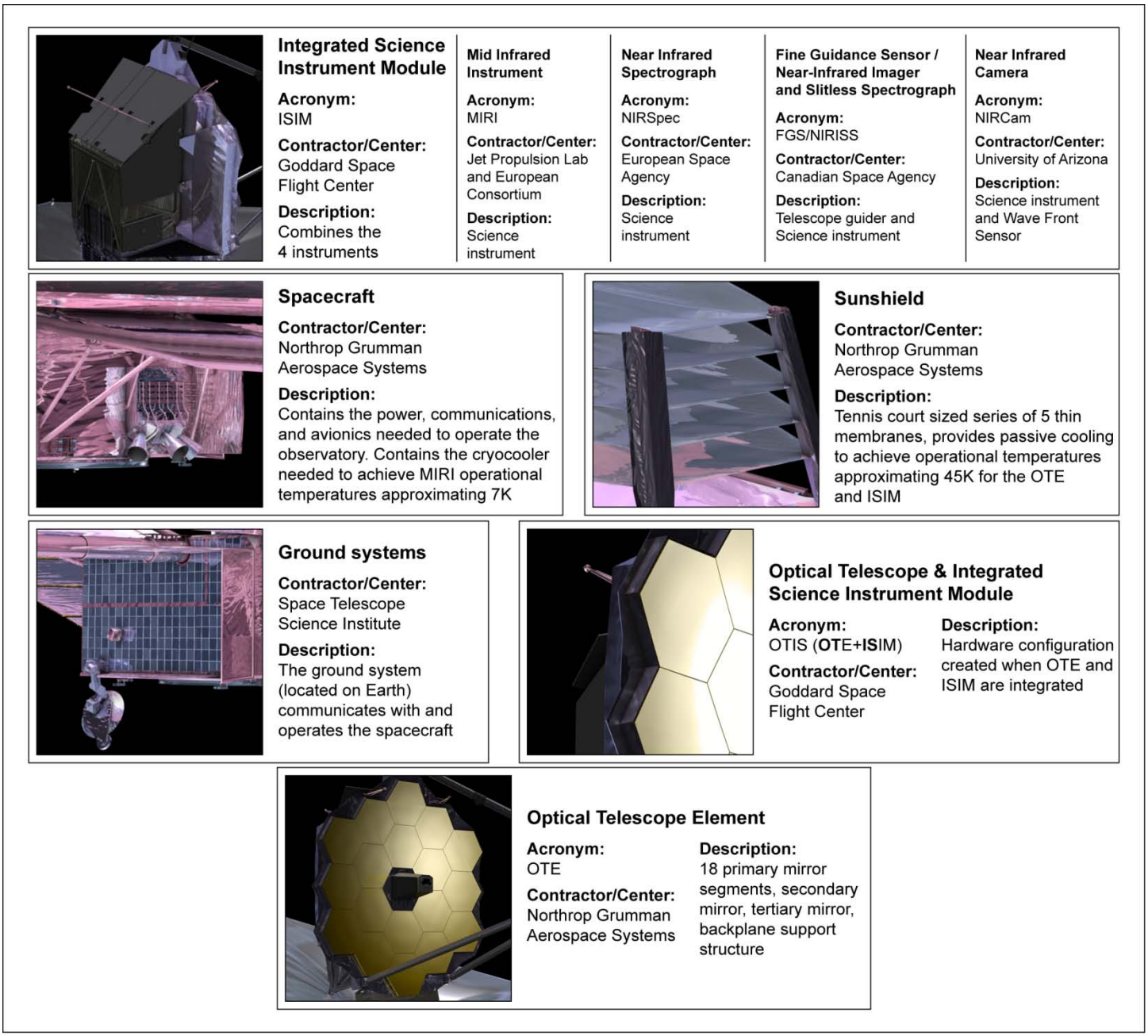
Institute concerning project oversight of work they were performing and the effectiveness of oversight changes. In addition, we reviewed a presidential directive and Office of Management and Budget and project documentation and interviewed project officials concerning the reductions to travel budgets and their impact on project oversight activities. We interviewed the Director of NASA's Office of Evaluation about a recent internal review of the JWST project and reviewed documentation from that review. We also reviewed documentation and interviewed project officials concerning the changes made to the project's risk management system.

Our work was performed primarily at NASA Headquarters in Washington, D.C., and Goddard Space Flight Center in Greenbelt, Maryland. We also visited Johnson Space Center in Houston, Texas, and the Jet Propulsion Laboratory in Pasadena, California. In addition, we met with representatives from Northrop Grumman Aerospace Systems, Lockheed Martin Advanced Technology Company, Teledyne Imaging Sensors, the University of Arizona, and the Space Telescope Science Institute.

We conducted this performance audit from February 2012 to December 2012 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

# Appendix II: Subsystems of the JWST Observatory

**Figure 8: Subsystems of the JWST: Interactive Information**




Sources: GAO (analysis); NASA (data and images).

Note: The hardware configuration created when the Optical Telescope Element and the Integrated Science Instrument Module are integrated, referred to as OTIS, is not considered a subsystem by NASA, but we categorize it as such for ease of discussion.

# Appendix III: Our Evaluation of JWST's Cost Estimate Process

In determining that the National Aeronautics and Space Administration's (NASA) processes for developing the James Webb Space Telescope (JWST) cost estimate do not fully comply with best practices, we evaluated the project's cost estimation methods against our 2009 Cost Estimating and Assessment Guide. (See table 4.) We applied the following scale across the four categories of best practices:

- Not met: NASA provided no evidence that satisfies any portion of the criterion.
- Minimally met: NASA provided evidence that satisfies less than one-half of the criterion.
- Partially met: NASA provided evidence that satisfies about one-half of the criterion.
- Substantially met: NASA provided evidence that satisfies more than one-half of the criterion.
- Met: NASA provided complete evidence that satisfies the entire criterion.

**Table 4: Summary Assessment of JWST Cost Estimate Compared to Best Practices**

| Characteristic | Overall assessment | Best practice | Individual assessment |
|---|---|---|---|
| Comprehensive | Substantially met | The cost estimate includes all life-cycle costs. | Met |
| | | The cost estimate completely defines the program, reflects the current schedule, and is technically reasonable. | Substantially met |
| | | The cost estimate work breakdown structure is product oriented, traceable to the statement of work/objective, and at an appropriate level of detail to ensure that cost elements are neither omitted nor double counted. | Substantially met |
| | | The estimate documents all cost-influencing ground rules and assumptions. | Substantially met |
| Well documented | Partially met | The documentation should capture the source data used, the reliability of the data, and how the data were normalized. | Partially met |
| | | The documentation describes in sufficient detail the calculations performed and the estimating methodology used to derive each element's cost. | Minimally met |
| | | The documentation describes step-by-step how the estimate was developed so that a cost analyst unfamiliar with the program could understand what was done and replicate it. | Minimally met |
| | | The documentation discusses the technical baseline description, and the data in the baseline are consistent with the estimate. | Substantially met |
| | | The documentation provides evidence that the cost estimate was reviewed and accepted by management. | Substantially met |

| Characteristic | Overall assessment | Best practice | Individual assessment |
|---|---|---|---|
| Accurate | Partially met | The cost estimate results are unbiased, not overly conservative or optimistic and based on an assessment of most likely costs. | Partially met |
| | | The estimate has been adjusted properly for inflation. | Partially met |
| | | The estimate contains few, if any, minor mistakes. | Partially met |
| | | The cost estimate is regularly updated to reflect significant changes in the program so that it is always reflecting current status. | Partially met |
| | | Variances between planned and actual costs are documented, explained, and reviewed. | Minimally met |
| | | The estimate is based on a historical record of cost estimating and actual experiences from other comparable programs. | Partially met |
| Credible | Partially met | The cost estimate includes a sensitivity analysis that identifies a range of possible costs based on varying major assumptions, parameters, and data inputs. | Minimally met |
| | | A risk and uncertainty analysis was conducted that quantified the imperfectly understood risks and identified the effects of changing key cost driver assumptions and factors. | Partially met |
| | | Major cost elements were cross-checked to see whether results were similar. | Minimally met |
| | | An independent cost estimate was conducted by a group outside the acquiring organization to determine whether other estimating methods produce similar results. | Partially met |

Source: GAO analysis of NASA data.

# Appendix IV: Comments from the National Aeronautics and Space Administration

National Aeronautics and Space Administration
**Office of the Administrator**
Washington, DC 20546-0001

NOV 20 2012

Ms. Christina Chaplain
Director
Acquisition and Sourcing Management
United States Government Accountability Office
Washington, DC 20548

Dear Ms. Chaplain:

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to review the Government Accountability Office (GAO) draft correspondence entitled "James Webb Space Telescope: Actions Needed to Improve Cost Estimate and Oversight of Test and Integration" (GAO-13-4). NASA values the continued open communications between NASA and the GAO team on the James Webb Space Telescope (JWST) and appreciates the constructive comments arising as a result of this dialogue. The JWST Program is fully compliant with NASA's programmatic requirements and is committed to making improvements as the Agency deems appropriate.

In the draft report, GAO makes two recommendations to the Administrator, specifically:

**Recommendation 1:** To ensure that the JWST life-cycle cost estimate conforms to best practices, GAO recommends that the NASA Administrator direct JWST project officials to take the following three actions to provide high-fidelity cost information for monitoring project progress:

a) improve cost estimate documentation and continually update it to reflect earned value management actual costs and record any reasons for variances,
b) conduct a sensitivity analysis on the number of staff working on the program to determine how staff variations affect the cost estimate, and
c) perform an updated integrated cost/schedule risk analysis, or joint cost and schedule confidence level analysis, using a schedule that meets best practices and includes enough detail so that risks can be appropriately mapped to activities and costs; historical, analogous data should be used to support the risk analysis.

**Management's Response: Partially Concur.**
1a) Partially Concur: NASA uses a number of performance metrics to assess the project's performance against plan, including Earned Value Management (EVM). NASA is currently receiving EVM data from multiple JWST contractors (i.e., Northrop Grumman Aerospace Systems [NGAS], Lockheed Martin Advanced Technology Center [LMATC], ITT/Exelis), and performs monthly analysis of that data to understand contractor estimates at completion (EAC) as compared to the Project's Independent EAC

1

(IEAC), documenting the reasons for any variances. NASA has also recently initiated EAC analysis for in-house Integrated Science Instrument Module (ISIM) work. NASA will continue to perform this analysis throughout the development phase of JWST.

NASA is committed to improving its documentation of the variances and to extending the EVM analysis to include areas where it is not yet implemented. For example, NASA is working with the Space Telescope Science Institute (STScI) to implement EVM for its ground system development. In addition, the Agency's annual budget planning activity (Planning, Programming, Budgeting, and Execution, or PPBE) generates a requirements-driven budget plan consistent with the rebaseline, which is well documented with Basis of Estimates (BOEs) and incorporates information on performance-to-date against plan and EAC estimates. JWST does not plan to revise its Joint cost and schedule Confidence Level (JCL) documentation developed during the re-plan.

1b) Partially Concur. NASA met the intent of this recommendation by taking a number of steps to determine how staffing variations affect its cost estimate and to ensure the project has sufficient margin to address changes in workforce requirements. Staffing levels, such as the number of full-time equivalents working on a specific activity at any given time, were determined in the 2011 JWST rebaseline based on programmatic experience in the accomplishment of similar activities. The primary driver of increased staffing hours required for a specific activity would be an increase in the duration of the activity (e.g., integration and test). To accommodate this possibility, funded schedule reserve was built into the 2011 JWST rebaseline in many areas including the NGAS contract, ISIM, and also at the JWST Project level. This funded schedule reserve is in addition to Unallocated Future Expenses (UFE) held by NGAS, ISIM, the JWST Project, and the JWST Program.

In addition, the integrated cost, schedule, and risk analysis (JCL) performed as part of the 2011 JWST rebaseline addressed the effect of changes in the duration of activities on staffing costs, the largest driver of Program cost. In the JCL analysis, the duration of activities are simulated as being both shortened and lengthened, enabling a calculation of the resultant cost associated with those variations in duration. Thus, the JCL analysis provided a defacto workforce sensitivity analysis.

Consequently, because of the funded schedule reserve and UFE built-in to the rebaseline and the JCL analysis, NASA considers that there is sufficient funded schedule reserve and UFE to cover increases in the duration of specific activities that result in increased staffing cost and that additional workforce sensitivity analysis is not warranted. NASA believes it met the intent of this recommendation and requests it be closed without requiring further action.

1c) Concur. To ensure the ongoing viability of the Project's plan, NASA performs monthly integrated programmatic and cost/schedule risk analyses through its assessments and updates of the Project's risks, costs and schedule to reflect actual progress and

changes to-date. For example, JWST conducts ongoing risk management by identifying risks, assigning probability to the risks, and determining a dollar value of each risk; assesses encumbrances/liens/threats against its UFE; tracks actual costs against planned costs to assess the viability of current estimates; uses earned value management, including independent estimates at complete that are factored into cost estimates; and performs schedule analyses. NASA uses these tools and methods to conduct ongoing programmatic assessment of projects after the baseline is established using the JCL methodology at KDP-C.

**Recommendation 2:** To ensure that technical risks and challenges are being effectively managed and that sufficient oversight is in place and can be sustained, GAO recommends that the NASA Administrator direct JWST project officials to take the following three actions:

a) conduct a separate independent review prior to the beginning of the OTIS and spacecraft integration and test efforts to allow the project's independent standing review board the opportunity to evaluate the readiness of the project to move forward, given the lack of schedule flexibility once these efforts are underway,
b) schedule the management review and approval to proceed to integration and test (key decision point D or KDP-D) prior to the start of observatory integration and test effort, and
c) devise an effective, long-term plan for project office oversight of its contractors that takes into consideration the anticipated travel budget reductions.

**Management's Response: Partially concur.**

2a) Concur. The current Optical Telescope element-Integrated Science instrument module (OTIS) integration and test plan includes a Pre-Environmental Review (PER) prior to environmental testing of OTIS. Currently, that review is conducted by a NASA Goddard Space Flight Center (GSFC) Independent Review Team (IRT) composed of independent technical reviewers from the Center and chaired by the Center's Mission Assurance organization, reporting their findings to the Center Director. In response to this GAO recommendation, JWST Standing Review Board (SRB) members will be requested to participate in the OTIS PER as well as co-chair the review and report their findings to the Decision Authority, the NASA Associate Administrator (AA), as is the practice for all JWST SRB reviews.

Because the spacecraft integration is a separate activity taking place at a different location than OTIS integration, to not unduly delay OTIS or spacecraft element integration and test, the current plan calls for the spacecraft developer (NGAS) to conduct a spacecraft element integration readiness review. In response to this GAO recommendation, NASA will direct NGAS to add members of the JWST SRB to this review as well as include some members of the GSFC IRT and report the review findings to the NASA AA.

The System Integration Review (SIR), a JWST SRB review scheduled for 2017, will remain a part of the review plan.

2b) Partially concur. Consistent with NASA policy, the SRB-chaired SIR is scheduled prior to the integration of the JWST science payload (OTIS) and the spacecraft element (consisting of the spacecraft bus and sunshield) with the SRB providing an independent assessment report to the NASA Decision Authority (NASA AA) within one week of the SIR prior to the beginning of observatory I&T. To respond specifically to this recommendation, the currently scheduled 3-month period between the SIR and KDP-D will be reduced, thereby providing NASA management and the NASA AA with the full independent assessment earlier than currently planned.

2c) Concur. NASA will develop a plan based on FY2013 travel allocations and will take into consideration anticipated travel budget reductions. The plan will enable the Project to maintain oversight of JWST contractors and their ability to meet performance and delivery deadlines and work closely with the Project's international partners.

Thank you for the opportunity to comment on this draft report. If you have any questions or require additional information, please contact Ray Taylor at (202) 358-0766.

Sincerely,

Eric D. Smith
for

Geoffrey Yoder
JWST Program Director

# Appendix V: GAO Contact and Staff Acknowledgments

## GAO Contact

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

## Staff Acknowledgments

In addition to the contact named above, Shelby S. Oakley, Assistant Director; Karen Richey, Assistant Director; Richard A. Cederholm; Laura Greifner; Cheryl M. Harris; David Hulett; Jason Lee; Kenneth E. Patton; Sylvia Schatz; Stacey Steele; Roxanna T. Sun; Jay Tallon; and Jade A. Winfree made key contributions to this report.