United States Government Accountability Office

Report to Congressional Committees

July 2016

ORION MULTI-PURPOSE CREW VEHICLE

Action Needed to Improve Visibility into Cost, Schedule, and Capacity to Resolve Technical Challenges

GAO-16-620

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GAO Highlights

Highlights of GAO-16-620, a report to congressional committees

Why GAO Did This Study

Orion is NASA's first crew capsule that could transport humans beyond the moon. Recent programs, such as Constellation, were canceled in the face of acquisition problems and funding-related issues. The $11 billion that NASA estimates it will need to develop Orion through 2023, along with the funding necessary for other human spaceflight programs, represents a significant portion of NASA's anticipated budget during that period.

The House Committee on Appropriations included a provision in its report for GAO to review the acquisition progress of Orion, among other human spaceflight programs. This report assesses (1) technical challenges facing the Orion program that may affect cost and schedule, (2) the reliability of Orion's cost and schedule estimates, and (3) agency and program programmatic decisions that may affect cost and schedule risks. To do this work, GAO examined documents supporting the cost and schedule estimates, contractor performance data, and other relevant program documentation, and interviewed relevant officials.

What GAO Recommends

To provide the Congress and NASA a reliable estimate of program cost and schedule, the program should perform an updated JCL analysis with cost and schedule estimates in line with best practices. The program should also perform an analysis to understand the impact of deferred work on program reserves. NASA partially concurred with the first recommendation and concurred with the second.

View GAO-16-620. For more information, contact Cristina Chaplain at (202) 512-4841 or chaplainc@gao.gov.

What GAO Found

The National Aeronautics and Space Administration's (NASA) Orion Multi-Purpose Crew Vehicle (Orion) program has overcome several technical challenges and made design changes to the crew capsule to reduce risk. Known challenges, however, remain—such as development of the service module and the crew capsule heatshield, among others—that could cause cost increases and schedule delays as the program undergoes integration and test. Technical challenges are inherent in complex programs such as Orion, but if not carefully managed, they could result in cost overruns and schedule delays. For example, the program has identified software development as an area of substantial risk with a potential cost impact of more than $90 million and which may result in schedule delays.

GAO found that the Orion program's cost and schedule estimates are not reliable based on best practices for producing high-quality estimates. Cost and schedule estimates play an important role in addressing technical risks. In September 2015, NASA established a commitment baseline of $11.3 billion and an April 2023 launch readiness date for the program's second exploration mission. NASA used a joint cost and schedule confidence level (JCL) analysis—a point-in-time estimate that, among other things, includes all cost and schedule elements and incorporates and quantifies known risks—to establish the commitment baselines at a 70 percent confidence level, as required by NASA policy. However, NASA's JCL analysis was informed by its unreliable cost and schedule estimates. GAO found that the Orion cost estimate met or substantially met 7 of 20 best practices and its schedule estimate met or substantially met 1 of 8 best practices. For example, the cost estimate lacked necessary support and the schedule estimate did not include the level of detail required for high-quality estimates. Without sound cost and schedule estimates, decision makers do not have a clear understanding of the cost and schedule risk inherent in the program or important information needed to make programmatic decisions.

NASA and the Orion program have made some programmatic decisions that could further exacerbate cost and schedule risks. The Orion program is executing to an internal schedule with a launch readiness date of August 2021, which has a lower confidence level than its commitment baseline. This means that NASA is accepting higher cost and schedule risk associated with executing this schedule. Working toward a more aggressive goal is not a bad practice; however, increasing cost and schedule risk to the program in order to pursue such a goal may not be a beneficial strategy to the program in the long term. According to program officials, the program employs most of its available budget to fund current work and holds most of its cost reserves at the end of the internal schedule. The lack of cost reserves has caused the program to defer work to address technical issues and stay within budget. As a result, the Orion program's reserves in future years could be overwhelmed by work being deferred. Program officials told GAO that they have not performed a formal analysis to understand the impact that delaying work might have on the available reserves since the program was confirmed. Without this type of analysis, program management may not have a complete understanding of how decisions made now will affect the longer-term execution of the program.

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Abbreviations

CDR	critical design review
EM-1	Exploration Mission 1
EM-2	Exploration Mission 2
ESA	European Space Agency
EVM	earned value management
JCL	joint cost and schedule confidence level
JWST	James Webb Space Telescope
KDP	key decision point
MDR	mission definition review
NASA	National Aeronautics and Space Administration
Orion	Orion Multi-Purpose Crew Vehicle
PDR	preliminary design review
SDR	system definition review
SIR	system integration review
SLS	Space Launch System
SRB	Standing Review Board
UFE	unallocated future expenses

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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July 27, 2016

The Honorable Richard C. Shelby
Chairman
The Honorable Barbara A. Mikulski
Ranking Member
Subcommittee on Commerce, Justice, Science, and Related Agencies
Committee on Appropriations
United States Senate

The Honorable John Culberson
Chairman
The Honorable Mike Honda
Acting Ranking Member
Subcommittee on Commerce, Justice, Science, and Related Agencies
Committee on Appropriations
House of Representatives

The National Aeronautics and Space Administration (NASA) is in the midst of developing the first crew capsule planned to be capable of transporting humans to multiple destinations beyond the moon and into deep space—the Orion Multi-Purpose Crew Vehicle (Orion). While NASA intends for Orion to provide an important capability for planned human exploration missions, the agency's attempts over the past two decades at developing a human transportation capability beyond low-Earth orbit have ultimately been unsuccessful. Predecessor programs, the most recent being the Constellation program, were canceled in the face of acquisition problems and funding-related issues. The $11 billion in funding that NASA estimates it will need to spend developing Orion through the first crewed exploration flight scheduled for no later than April 2023, along with the funding necessary for its launch vehicle—the Space Launch System (SLS)—and the associated ground systems, represents a significant portion of NASA's anticipated budget during that period.

GAO has designated NASA's management of acquisitions as a high-risk area for more than two decades. In 2015, we found that the agency had made progress in reducing risk on major projects after years of struggling with poor cost estimation, weak oversight, and risk underestimation. We also found, however, that demonstrating that this progress can be translated to larger, more complex projects, such as Orion, will be especially important in an era of constrained budgets and competing priorities, and any cost or schedule overrun on these large programs

could have a ripple effect on NASA's portfolio with the potential to postpone or even cancel altogether projects in earlier stages of development.[1]

Establishing an exploration program that will be affordable and sustainable for the long term is also a key guideline in the 2013 National Space Transportation Policy.[2] The House Committee on Appropriations raised questions about the long-term cost, progress, and risks associated with NASA's human spaceflight efforts and the lack of insight into these programs that NASA has provided the Congress, and includes a provision in its report for GAO to review acquisition progress of NASA's human exploration programs, including Orion, SLS, the Ground Systems Development and Operations, and Commercial Crew.[3] This report assesses (1) technical challenges facing the Orion program that may affect cost and schedule, (2) the reliability of the Orion program's cost and schedule estimates, and (3) agency and program programmatic decisions that may affect cost and schedule risks.

To assess the technical challenges facing the Orion program and the extent to which those challenges impact cost and schedule commitments, we obtained and reviewed copies of program documentation, including monthly and quarterly status reports, and data from the program's risk management system. We identified risks that we have previously found to pose technical challenges to the program and those that the program had detailed in its quarterly status reports to NASA management.[4] We obtained and analyzed contractor cost and schedule monthly reports—or earned value management (EVM) data—for the Orion program's prime contractor since May 2014, to determine the extent to which the data were consistent with EVM best practices identified in GAO's Cost

[1]GAO, *High Risk Series: An Update*, GAO-15-290 (Washington, D.C.: Feb. 11, 2015) and *NASA: Assessments of Selected Large-Scale Projects*, GAO-15-320SP (Washington, D.C.: Mar. 24, 2015).

[2]National Space Transportation Policy, November 21, 2013.

[3]H.R. Rep No. 114-130, at 60-61 (2015). We have separate ongoing work assessing the acquisition process of the SLS, Ground Systems Development and Operations, and Commercial Crew programs, and we plan to issue reports on these programs in 2016.

[4]GAO-15-320SP.

Estimating and Assessment Guide.[5] We assessed the reliability of the NASA EVM system and analyzed the data in order to understand contractor cost and schedule trends shown by the data. We provided preliminary findings to the Orion program. In addition, we assessed the extent to which NASA has insight into European Space Agency processes and schedules to develop portions of the service module by reviewing program documentation such as quarterly status reports, risk management system information related to the European Service Module, and the agreement between NASA and the European Space Agency that defines responsibilities for work on the European Service Module. We also interviewed Orion program officials regarding the work being performed by the European Space Agency and its prime contractor. To assess the reliability of the Orion cost and schedule estimates, we determined the extent to which the estimates were consistent with best practices for cost estimating and scheduling as identified in GAO's Cost Estimating and Assessment and Schedule Assessment guides.[6] We examined documents supporting the cost and schedule estimates and the timing and availability of funding and reserves as well as relevant NASA policy. We also met with members of the independent program review board within NASA and reviewed their report on the program's estimates and JCL. To assess agency and program programmatic decisions that may affect cost and schedule, we reviewed documents that detailed the proposed amount and availability of Orion program cost and schedule reserves, analyzed program budget documentation, and the Orion program's prime contractor EVM data for management reserve held by the contractor. We interviewed NASA and program officials with technical and programmatic knowledge of the program's formulation and development. In addition, we met with program management and program budget specialists to discuss the program's budget and reserve postures, and with prime contractor officials to discuss the management reserve being held by the contractor and how these reserves were used to mitigate known risks. Appendix I contains detailed information on our scope and methodology.

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

[6]GAO, GAO-09-3SP and *GAO Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-12-120G (Washington, D.C.: May 30, 2012).

We conducted this performance audit from September 2015 to July 2016 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

Orion began development in July 2006 as a project under NASA's Constellation Program. The 5-meter diameter Orion capsule—known at that time as the Crew Exploration Vehicle—was designed to be launched by the Ares I Crew Launch Vehicle and carry four astronauts and cargo to the International Space Station and to the moon. In 2009, we found that poorly constructed budgets had diminished the program's ability to deal with technical problems and funding shortfalls.[7] The Constellation program was proposed to be canceled by the President in fiscal year 2010 after an independent commission concluded that Constellation faced challenges to achieve its stated goals of returning humans to the moon by 2020. However, the NASA Authorization Act of 2010 required continued development of a crew vehicle, in part, to develop a capability to serve as the primary crew vehicle for missions beyond low-Earth orbit.[8]

In February 2012, the Orion project transitioned from Constellation as a new development program and was designated the Orion Multi-Purpose Crew Vehicle. To transition Orion from Constellation, NASA adapted the requirements from the former Orion plan with the other associated and newly created programs—SLS and the associated ground systems. The agency also used existing contracts to ensure that the program met requirements of the 2010 Act to utilize previous contracts to the extent practicable. Although NASA reported spending almost $5 billion through November 2010 on the former Orion project, NASA placed the new Orion program in an early phase of development. According to NASA officials, this placement was necessary at the time due to continued work on

[7]GAO, *NASA: Constellation Program Cost and Schedule Will Remain Uncertain Until a Sound Business Case Is Established*, GAO-09-844 (Washington, D.C.: Aug. 26, 2009).

[8]Pub. L. No. 111-267, § 303.

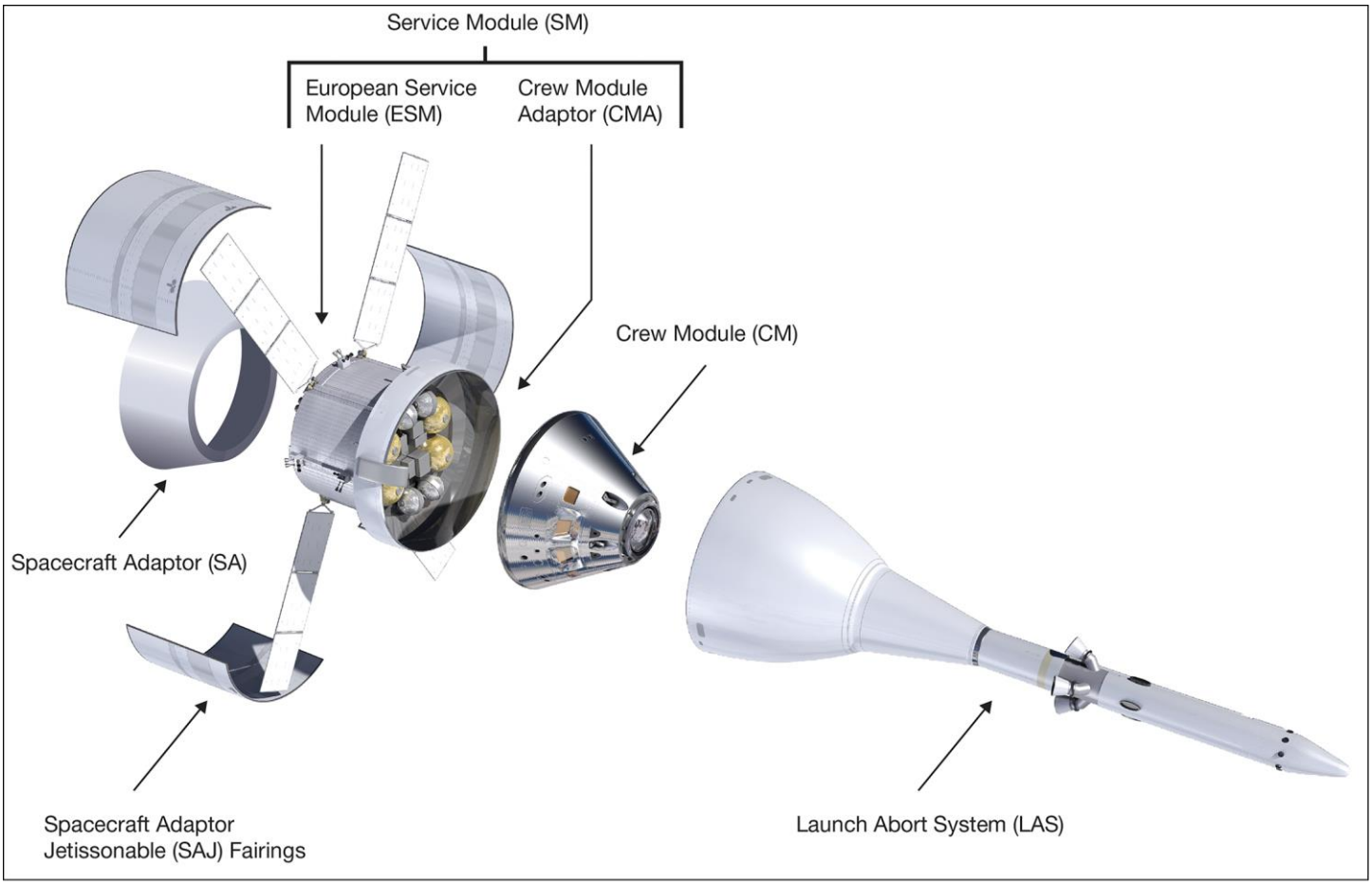
refining budget estimations and in order to align Orion requirements with both the SLS and ground systems programs.

In December 2014, the Orion program successfully launched an exploration flight test on a Delta IV Heavy launch vehicle. Although the capsule used in this test flight did not meet all of the requirements of a fully capable Orion, this 4-hour mission provided data to better inform cost and schedule estimates as well as improved design modelling for several key processes and technologies. The Orion program currently plans for two future exploration missions—Exploration Mission-1 (EM-1) and Exploration Mission-2 (EM-2)—launched atop an SLS launch vehicle. EM-1 is scheduled to be an uncrewed mission that will fly some 70,000 kilometers beyond the moon. This mission is expected to demonstrate spacecraft systems performance, a high-speed re-entry, and performance of the thermal protection system prior to a crewed flight. This 25-day mission will culminate with a landing off the coast of California. EM-2 is scheduled to be a 10- to 14-day crewed flight with up to four astronauts that will orbit the moon and return to Earth to demonstrate the baseline Orion vehicle capability. NASA has not established specific launch dates for either EM-1 or EM-2. The agency plans to establish a launch date for EM-2 after the EM-1 mission is complete.

Elements of Orion

The current design of Orion builds upon the development done during Constellation and consists of a crew module, service module, and launch abort system. See figure 1.

Figure 1: Orion Program Hardware Components



Source: National Aeronautics and Space Administration (NASA) /Orion Program. | GAO-16-620

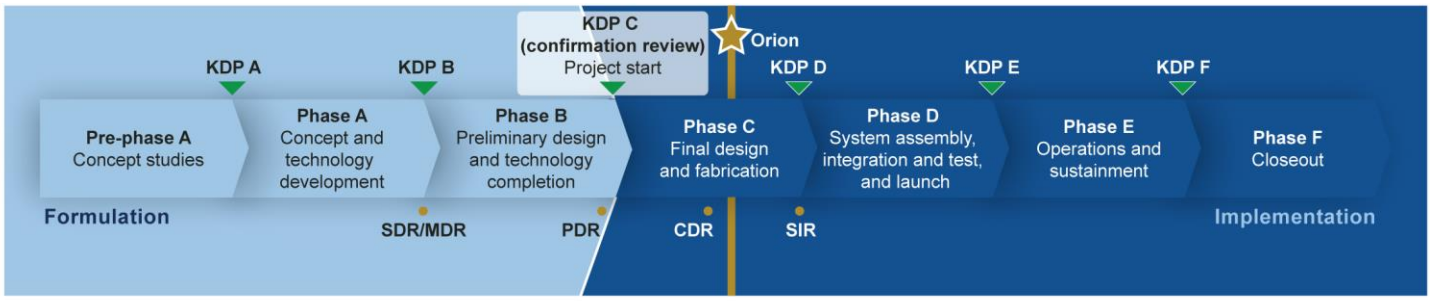
The crew module will provide a habitable pressurized volume to support crewmembers and cargo during all elements of a given mission from launch operations to Earth entry, descent, landing, and recovery. The service module is comprised of the two subcomponents, the Crew Module Adapter and the European Service Module, and provides services to the crew module in the form of propulsion, consumables storage, heat rejection and power generation. In December 2012, NASA signed an implementing agreement, or what officials refer to as a barter agreement, with the European Space Agency (ESA) to produce the European Service Module for the first exploration mission with an option for ESA to produce an additional unit for the second exploration mission. As part of the barter

agreement, ESA will provide NASA the European Service Module for the first exploration mission to offset a part of ESA's cost responsibility for the International Space Station program, among other things. The launch abort system will provide an abort capability to safely transport the crew module away from the launch vehicle in the event of an emergency on the launch pad or during ascent.

NASA's Acquisition Life Cycle

NASA plans to develop Orion following the agency's life-cycle acquisition process for flight systems. That process is defined by two broad phases—formulation and implementation—and several key decision points. These broad phases are then further divided into incremental pieces with different purposes: pre-phase A through phase F. See figure 2 for a depiction of NASA's life cycle for flight systems.

Figure 2: NASA's Life Cycle for Space Flight Projects



Management decision reviews

▼ KDP = key decision point

Technical reviews

- SDR/MDR = system definition review/mission definition review
- PDR = preliminary design review
- CDR = critical design review
- SIR = system integration review

Source: National Aeronautics and Space Administration (NASA) data and GAO analysis. | GAO-16-620

Formulation culminates in a review at key decision point (KDP) C, known as project confirmation, where cost and schedule baselines are established and documented in a decision memorandum. The decision memorandum outlines the management agreement and the agency baseline commitment. In this report, we refer to the Orion management agreement as the program's internal goal. According to NASA policy, the internal goal can be viewed as a contract between the agency and the

project manager. The project manager has the authority to manage the project within the parameters outlined in the agreement. The agency baseline commitment establishes the cost and schedule baselines against which the project may be measured. To inform the internal goal and the agency baseline commitment, each project with a life-cycle cost estimated to be greater than $250 million must also develop a joint cost and schedule confidence level (JCL). The JCL initiative, adopted in January 2009, is a point-in-time estimate that, among other things, includes all cost and schedule elements, incorporates and quantifies known risks, assesses the impacts of cost and schedule to date, and addresses available annual resources.

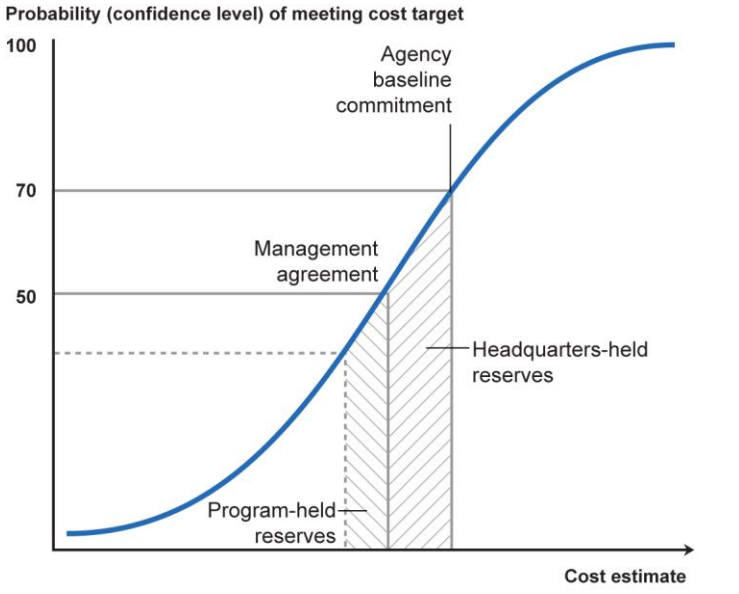
In our prior work on the SLS program and the James Webb Space Telescope (JWST) project, we found that the cost and schedule estimates that support these program's JCLs were not fully reliable.[9] In July 2015, we found that the SLS program estimates substantially complied with most relevant best practices, but could not be deemed fully reliable because they only partially met the best practice for credibility. While an independent NASA office reviewed the SLS estimate developed by the program and the program made some adjustments based on that review, officials did not commission the development of a separate independent estimate to compare to the program estimate to identify areas of discrepancy or difference in accordance with best practices. In addition, the program did not cross-check its estimate using an alternative methodology. We recommended that the SLS program update its cost and schedule estimates at least annually to reflect actual costs and schedule and record any reasons for variances before preparing its budget requests for the ensuing fiscal year. NASA concurred with our recommendation. Further, in December 2012, we found that the accuracy of the JWST's estimate—and therefore the confidence level assigned to the estimate—was lessened by the summary schedule used for the JCL because it did not provide enough detail to determine how risks were applied to critical project activities. The JWST estimate's credibility was also lessened because officials did not perform a sensitivity analysis that

[9]GAO, *James Webb Space Telescope: Actions Needed to Improve Cost Estimate and Oversight of Test and Integration*, GAO-13-4 (Washington, D.C.: Dec. 3, 2012) and *Space Launch System: Management Tools Should Better Track to Cost and Schedule Commitments to Adequately Monitor Increasing Risk*, GAO-15-596 (Washington D.C.: July 16, 2015).

would have identified key drivers of costs, such as workforce size. At that time, we recommended that the JWST project update its cost and schedule risk analysis. NASA concurred with our recommendation but has not updated its analysis.

NASA policy requires that projects be baselined and budgeted at the 70 percent confidence level, which is used to set the cost and schedule targets in the agency baseline commitment, and funded at a level equivalent to at least the 50 percent confidence level, which is used to set the targets for the project's management agreement—or what we refer to in this report as the Orion program's internal goal. According to NASA officials, this would include cost reserves held at the directorate and project level to address project risks. The total amount of reserves held at the project level varies based on where the project is in its life cycle. Figure 3 notionally depicts how NASA would allocate funding reserves for a project that was baselined in accordance with policy.

Figure 3: Notional Allocation of Funding Reserves for a Project Budgeted at the 70 Percent Confidence Level



Source: GAO analysis of National Aeronautics and Space Administration (NASA) policy. | GAO-16-620

After a project is confirmed, it begins implementation, consisting of phases C, D, E, and F. In this report, we refer to projects in phase C and D as being in development. A second design review, the critical design review (CDR), is held during the latter half of phase C in order to determine if the design is stable enough to support proceeding with the final design and fabrication. For example, a CDR before the project's subsystems are integrated evaluates the integrity of the project design and its ability to meet mission requirements, with appropriate margins and acceptable risk, within defined project constraints, including available resources. In short, the CDR determines if the design is appropriately mature to support proceeding with the final design and fabrication phase. Our past work on product development best practices has found that programs having at least 90 percent of engineering drawings releasable by the critical design review lower their risk of subsequent cost growth and schedule delays, and guidance in NASA's Systems Engineering Handbook mirrors this metric.[10] After the CDR and just prior to beginning phase D, the project completes a system integration review to evaluate the readiness of the project and associated supporting infrastructure to begin system assembly, integration and test.

Orion Program Is Addressing Known Technical Challenges, but Faces Potential Cost Increases on Prime Contract

Technical risks are inherent to complex programs such as Orion and the program has made strides in mitigating known challenges. For example, the program is implementing a solution to address a risk to crew safety when the parachutes deploy during landing. The program is currently tracking several technical issues that could cause cost increases and schedule delays, some of which could affect the launch schedule for EM-1 that would also affect the SLS program and the associated ground systems. For example, the Orion program is tracking issues with development of the European Service Module and requalification of Space Shuttle-era engines that could increase development costs and extend the schedule by several months. The program did not fully assess some of the technical issues facing the program at its critical design

[10]GAO, *NASA: Implementing a Knowledge-Based Acquisition Framework Could Lead to Better Investment Decisions and Project Outcomes*, GAO-06-218 (Washington, D.C.: Dec. 21, 2005); *Best Practices: Using a Knowledge-based Approach to Improve Weapon Acquisition*, GAO-04-386SP (Washington, D.C.: Jan. 1, 2004); *Best Practices: Better Acquisition Outcomes Are Possible If DOD Can Apply Lessons from F/A-22 Program*, GAO-03-645T (Washington, D.C.: Apr. 11, 2003); and NASA, *Systems Engineering Handbook,* NASA/SP-2007-6105 Rev1 (Washington, D.C.: December 2007).

review in October 2015, a decision which did not follow acquisition best practices. In addition, the Orion program's prime contractor has underperformed over the past 2 years since the contract was modified to extend the period of performance through December 2020. Specifically, our analysis of contractor data has shown that the program faces potential cost overruns of up to $707 million and work is costing more than expected and not being accomplished as scheduled. According to Orion program officials, the program has adequate reserves to manage cost growth of this magnitude. While the amount of reserves the program has planned would be able to absorb this potential cost overrun, the program's ability to address other technical issues that may arise with its reserves could be limited.

Program Has Made Progress Addressing Some Technical Challenges, but Additional Risks May Further Affect Cost and Schedule

The Orion program has overcome several technical challenges and made design changes to the capsule to reduce risk, including the following:

- The program is implementing a solution regarding a risk associated with the process for parachute deployment during landing. In 2015, we found that the program had identified that the parachutes begin to swing past each other, creating a "pendulum effect" when only two of the three main parachutes are deployed.[11] This effect could cause the capsule to increase speed and land incorrectly for a safe water landing. The program is taking steps to mitigate this effect on re-entry by delaying the parachute deployment and modifying the capsule's hanging angle.
- The program used information from the December 2014 flight test to modify the design of the crew module primary structure. Based on the test flight, the program determined that it was able to use fewer, larger structural panels and reduce the number of structural welds, which simplifies the design and manufacturability of the capsule. Program officials stated that improvements in manufacturing could ultimately reduce production costs of follow-on capsules.
- The program has reduced the mass of the crew module, which has been a continual concern for the Orion program. Structural changes, such as the crew module design modifications noted above, have allowed the program to reduce the overall mass of the capsule. The

[11]GAO-15-320SP.

program, however, is still conducting mass reduction efforts and is tracking risks for mass at liftoff and landing for EM-2.

The program still faces several technical challenges that may have cost or schedule implications, some of which could affect the launch schedule for EM-1 and would also affect the SLS program and the associated ground systems. Such risks are not unusual for large-scale programs and programs of this complexity, especially human exploration programs that are inherently complex and difficult. Nevertheless, these risks require close attention as they could require additional time and money to resolve if not effectively managed. Further, the program has entered its integration and test phase for EM-1, which may also require additional resources. Our prior work has shown that this period often reveals unforeseen challenges leading to cost growth and schedule delays.[12] Known risks being tracked by the program that could affect the program's cost and schedule include the European Service Module, re-use of heritage technology that will require re-qualification for use on Orion, the still-evolving design of the capsule heatshield, and software development.

European Service Module

The program is tracking development and integration of the European Service Module as a program risk that could potentially affect the program cost and schedule. NASA is working with ESA and its prime contractor via what officials refer to as a barter agreement concerning Orion rather than a contract mechanism. According to program officials, ESA is responsible for overseeing the contract with its prime contractor, and NASA is involved in determining value of work as it is applied to the barter. The program does have insight into the technical details of production and the progress being made on the European Service Module, but the program has little ability to affect the module's schedule, since it does not directly oversee the work. ESA has experienced several delays in the development of the European Service Module. These delays have affected the schedule delivery date for the European Service Module flight hardware to the Orion program and its prime contractor that will be responsible for its integration with other service module components, and has made the European Service Module delivery one of the competing

[12]For example, GAO, GAO-15-596; *NASA: Assessments of Selected Large-Scale Projects*, GAO-13-276SP (Washington D.C.: Apr. 17, 2013; and *James Webb Space Telescope: Project on Track but May Benefit from Improved Contractor Data to Better Understand Costs*, GAO-16-112 (Washington, D.C.: Dec. 17, 2015).

critical paths for the program. Further delays to the European Service Module could result in delays to the EM-1 launch schedule. The Orion program indicates that it has an agreement with ESA whereby ESA will provide monthly reporting of its metrics to allow NASA to better mitigate schedule shifts.

In addition, the European Service Module structural test article was delivered in November 2015 to NASA to begin testing—5 months behind the ESA prime contractor's committed schedule. NASA officials at Plum Brook Station—where the testing will be accomplished—told us that it arrived even later than they originally expected, given ESA planning documents shared with NASA had originally anticipated a December 2014 delivery date. Further, the test article was not complete when it arrived and ESA's prime contractor had to send contractors to complete work on the test article at Plum Brook Station. According to program officials, these delays have required the Orion program to adjust the test schedule at the Plum Brook facility, resulting in a success-oriented test schedule for this module. Any issues discovered during testing may affect other testing. For example, the Launch Abort System is scheduled to begin testing directly after the European Service Module test article and its schedule will be affected if there are delays in European Service Module testing. According to program officials, testing of the structural test article was on track as of the end of April 2016.

Further, NASA and ESA have agreed in principle that ESA will provide the European Service Module for EM-2, and NASA is negotiating with ESA to identify specific technical content required for EM-2. For example, NASA has requested changes to the European Service Module for EM-2 such as design changes to make the module compatible with a new upper stage for the SLS launch vehicle. According to program officials, NASA has notified ESA of its intent to exercise the option to the barter agreement for the European Service Module for EM-2 and discussions between the agencies are on-going to identify possible barter items. Officials added that a formal decision by ESA will not come until the end of calendar year 2016. The program continues to track the European Service Module for EM-2 as one of the largest cost risks facing the program—an estimated €175 million or approximately $200 million. This is the cost identified in the barter agreement with ESA for which NASA could procure the European Service Module goods and services directly, in the event that NASA and ESA do not reach an agreement on an acceptable barter for the second European Service Module.

Heritage Technology and Component Re-Use

NASA is also tracking several risks with the engine for the service module due to the decision to use heritage technology. NASA is supplying Space Shuttle-era Orbital Maneuvering System Engines to ESA for use in the European Service Module to save time and the cost of developing and qualifying new engines for the service module. However, these engines will need to be re-qualified because the operating environment for Orion will be significantly different than the Space Shuttle. For example, NASA began tracking a risk in July 2015 for this re-qualification process, which will involve several acceptance tests and initially estimated a potential schedule impact of between 3 and 6 months and a cost impact of as much as $450 million. According to program officials, however, following a reevaluation of possible mitigation options the potential cost impact is no more than $30 million and officials stated that the EM-1 flight unit is tracking no more than one month behind the original planned delivery date. As of January 2016, the program began tracking a separate risk on the same engines due to the different thermal environments for Orion and the Space Shuttle that could result in a delivery delay of those engines of up to 12 months if another test is needed.

In addition to re-purposing heritage technology, the program is planning to re-use some EM-1 components on EM-2, including the avionics system for the crew capsule. Any anomalies or perturbations in EM-1's flight have the potential to impact EM-2's schedule, as equipment earmarked for re-use may need to be repaired, re-designed, or rebuilt. The program's Standing Review Board (SRB)—which consists of experts from related fields, mostly from within NASA but independent of the program, who provide the program and NASA senior management with an objective assessment of the program's progress, issues, and risks—expressed concerns about this re-use strategy, noting that there are a high number of interdependencies in the program as a result, and a test failure of one of the multi-use elements would have a significant impact on the program.[13] In order to provide a back-up plan, the program is exploring

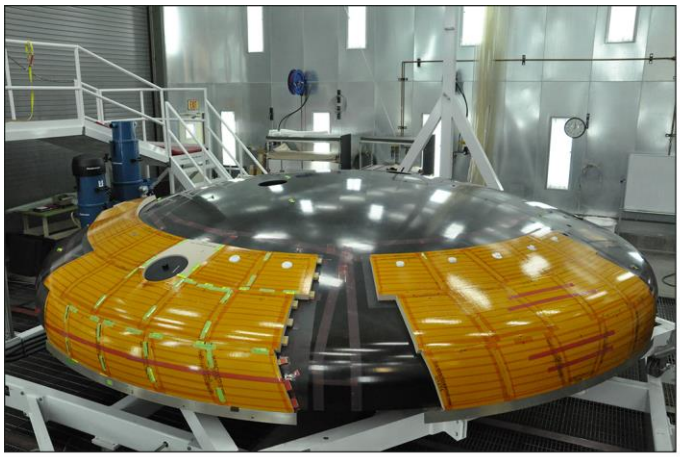
[13]The SRBs for each program have been maintained under the auspices of NASA's Independent Program Assessment Office. However, that office has recently been dissolved by the agency and its functions—including identification and approval of SRB members, monitoring compliance with NASA policy, and providing independent analysis—will be largely overseen by the mission directorates responsible for the individual programs. As we noted in March 2016, we will continue to monitor the potential impacts of this reorganization as it unfolds.

options to purchase another avionics kit for EM-2 that would take EM-2's avionics off the critical path identified by the program for EM-2.

Heatshield Redesign

The Orion program is currently redesigning its heatshield based on the results of the December 2014 exploration flight test. NASA determined that not all aspects of the monolithic design used in this flight test will meet the more stringent requirements for EM-1 and EM-2, when the capsule will be exposed to greater temperature variance and longer durations. The program has decided to change from a monolithic design to a block heatshield design for EM-1. This design will adhere approximately 300 blocks to the support structure and apply filler material to the gaps between blocks, similar to the design used on the Space Shuttle. See figure 4.

Figure 4: The Orion Block Heatshield



Source: Lockheed Martin. | GAO-16-620

However, this block design also carries some risk because of uncertainty about the blocks' ability to adhere to the support structure, as well as performance of the gap filler material. The program completed non-destructive testing of the adhesive and filler in January 2016 and completed further testing to zero margin and failure parameters in February 2016. According to program officials, these tests showed that adherence to the support structure was improved and a greater flaw detection capability was achieved, and the program has additional testing planned. The program continued testing of the monolithic design as another form of risk mitigation. According to program officials, the program and NASA engineers completed the root cause assessment of

the cracking found on the monolithic design during the manufacturing process prior to the December 2014 exploration flight test, which found that excessive primer was applied to the heatshield structure that resulted in reduced adhesion. In addition, these officials added that the program has completed an assessment of the heatshield structure modifications required to increase the strength of the monolithic design, but the program plans to continue to pursue the block design.

Software Development and Testing

Software development is also a risk identified by the Orion program. Development of flight software has experienced delays and has led the Orion program to defer content into later releases. The software development schedule now includes additional releases and has resulted in delays to planned software releases for EM-2 content. As of March 2016, the program was still assessing the impact on EM-2 software development. Software was noted as an area of substantial risk by the program; of 74 risks noted in the program's risk management system, 12 were software related and have a potential impact over $90 million and potential to result in numerous schedule delays. In addition, the Integrated Test Lab facility where much of the software will be tested is oversubscribed. The facility will also host testing for SLS and the associated ground systems. Orion program officials told us that they have implemented options to reduce the oversubscription such as expanding the test facilities, using other test facilities, or reducing/deleting some test requirements.

Further, some of the program's technical challenges were not fully assessed at the mission CDR for EM-1 in October 2015, as NASA moved forward with this key technical review before it was prepared to do so, as evidenced by the following:

- The program had released only 68 percent of design drawings. GAO best practices dictate that design stability is evidenced by release of 90 percent of design drawings at CDR. Because the CDR is the time in a project's life cycle when the integrity of a project's design and its ability to meet mission requirements are assessed, it is important that a project's design is stable enough to warrant continuation with design and fabrication. A stable design allows projects to "freeze" the design and minimize changes prior to beginning the fabrication of hardware. It also helps to avoid re-engineering and rework efforts due to design changes that can be costly to the project in terms of time and funding. According to program officials, on-going engineering studies in some subsystems and a lack of engineering staff needed to complete the

drawings in the months prior to the CDR contributed to the low number of drawings released.

- The Orion program had not completed subsystem design reviews for several key hardware components—including the European Service Module and the heatshield—due to schedule delays and technical issues that needed to be addressed. Program officials indicated that mitigation plans were formally approved by the CDR board.
- The program did not assess the cost and schedule estimates as part of the CDR process to ensure they are credible and that adequate resources exist to complete development, which is required by NASA's systems engineering policy at CDR. Program officials said that because the program had just established the cost and schedule baselines a month earlier, the review board wanted to gather cost and schedule data for several months of execution before making that assessment, and NASA management was in agreement with this decision.

The program planned to hold a post-CDR review in May 2016, at which point it planned to carry out a final assessment of the cost and schedule estimates and the design of all the capsule's systems, even though the European Service Module's design was not ready to be assessed until June 2016.[14] The program noted that the delay in holding the European Service Module CDR would not impact the overall schedule, and that any pertinent results of that CDR would be presented to program management once that review has been completed. Moving forward with the post-CDR review without the results of the European Service Module CDR, however, could increase risk to the program if issues are discovered during this subsystem CDR that require design changes to other components.

Though EM-1 is designed to be a test flight for the crewed EM-2 mission that will follow, the program has already announced that it will hold the CDR for EM-2 in 2017—at least a year before EM-1 is scheduled to launch. This decision greatly reduces the program's ability to incorporate information gleaned or any necessary design changes derived from EM-1 into the design for EM-2. Further, should data from EM-1's flight prove to

[14]At the time of this report, the results of the program's post-CDR review were not yet available.

be outside expected parameters, design changes to EM-2 would likely impact both the program's cost and schedule. When the SRB reviewed the program's planning for EM-2, it found that there was a significant level of hardware drawing revisions and procurement updates—indicating that the program had not settled many of its designs, and could use data from the EM-1 flight to better prepare for EM-2. According to an Orion assistant program manager, holding the EM-2 CDR after the launch of EM-1 creates a programmatic risk of delaying EM-2. The official added that the program will be able to incorporate learning from EM-1 into the operations, software, and some aspects of later integration and testing in the current plan, and the risk of more significant changes due to failures or major redesigns would likely cause a schedule slip to EM-2 anyway.

Program Facing Potential Cost Increases as Contractor Performance Declines

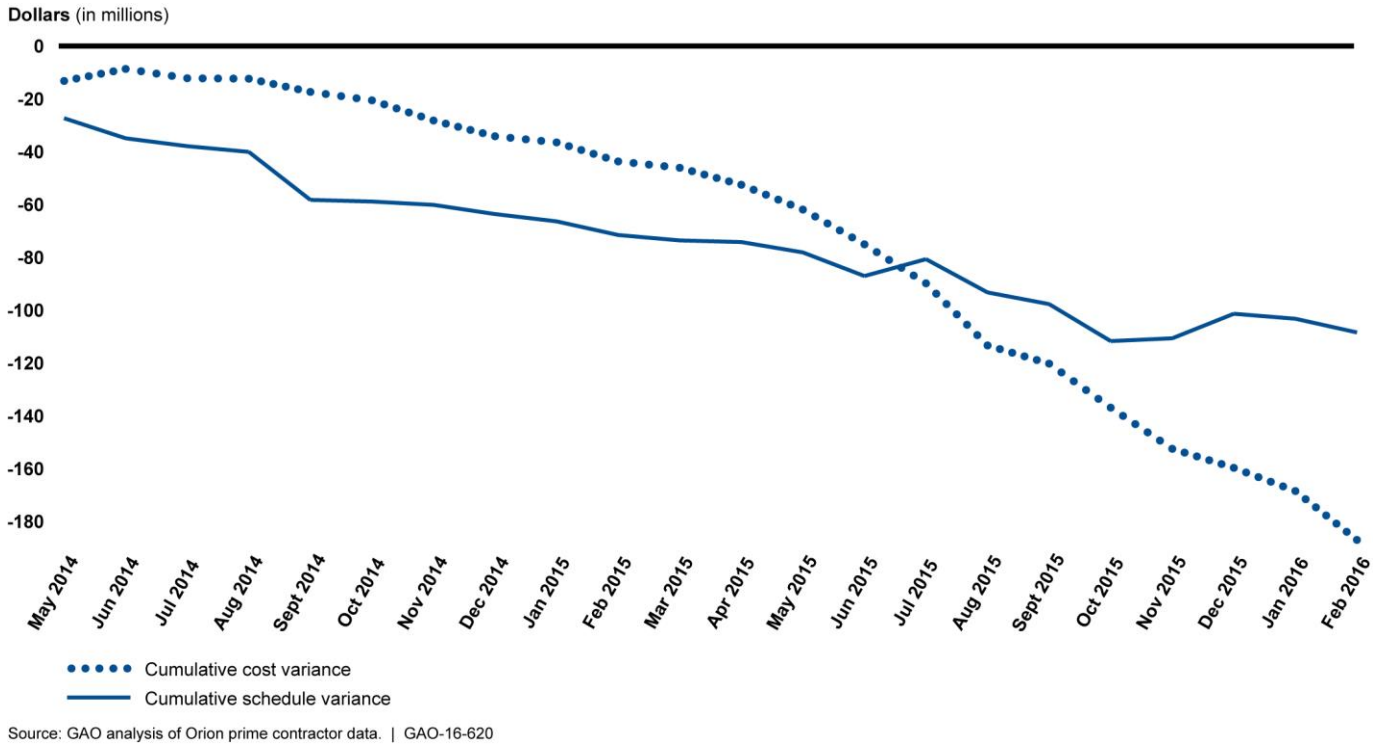
The Orion program's prime contractor—whose work makes up approximately 75 percent of the Orion program life cycle cost—is falling behind schedule, and work is costing more than originally estimated. The Orion program is following good project management practices by collecting and analyzing earned value management (EVM) data to track the performance of its prime contractor. EVM is an important project management tool that, when properly used, can provide accurate assessments of project progress, produce early warning signs of impending schedule delays and cost overruns, and provide unbiased estimates of anticipated costs at completion. Based on the EVM data generated through February 2016, our analysis found that the Orion program faces a potential cost overrun of between $258 million and $707 million through the end of the current contract in December 2020.[15] The prime contractor's EVM data also indicates potential cost overruns as the contractor expects the costs at completion of the contract to be between $360 million and $772 million more than budgeted for that contract. According to Orion program officials, the program has adequate reserves to manage cost growth of this magnitude. While the amount of reserves the program has planned would be able to absorb this potential cost overrun, the program's ability to address other technical issues that may arise with its reserves could be limited.

[15]We found that the prime contractor's EVM data was reliable—the system is comprehensive, outputs are reliable, and management is using the data for decision making purposes. See Appendix II for more detail of our assessment of this EVM data.

The contractor's performance, as measured using EVM data, has shown a negative cost and schedule trend since a contract re-baseline in February 2014 to extend the period of performance to December 2020, indicating that the program is falling behind schedule while the cost overruns are growing. Specifically, the cumulative cost variance and cumulative schedule variance through February 2016 has been increasingly negative since the performance baseline was reset in February 2014.[16] For example, the prime contractor has a negative cost variance of almost $187 million as of February 2016, indicating that nearly $190 million more was spent to complete the work than was budgeted for that work. See figure 5.

[16]Cost variance is calculated by taking the difference between the budgeted cost of completed work and its actual cost, while schedule variance is calculated by taking the difference between completed work and planned work. Positive variances indicate that the program is either underrunning cost or performing more work than planned. Conversely, negative variances indicate that the program is either overrunning cost or performing less work than planned.

Figure 5: Cumulative Cost and Schedule Variance for the Orion Prime Contract from May 2014 to February 2016



Source: GAO analysis of Orion prime contractor data. | GAO-16-620

Orion program officials identified several key drivers for this cost variance including delayed development of hardware for the command and data handling systems by a major subcontractor, needing increased labor support (including three-shift operations), and overcoming challenges to do with the capsule's mass, interface, and abort loads. See table 1 for the key drivers identified by the program and the risk mitigation strategies it is employing.

Table 1: Key Drivers of Cost and Schedule Variances and Mitigation Strategies Employed by the Orion Program

Major drivers of cost and schedule overruns	Mitigation strategies being employed
Production delays at a major subcontractor during component manufacturing and testing for the avionics, power, and wiring systems.	Forming joint contractor/subcontractor tiger teams to address the component designs and evaluating the labor volume for nonessential personnel, among other actions.
Assembly, Test, and Launch Operations variances are driven by additional projected labor support in fiscal year 2017 to support an additional crew module (and test articles) in the workflow and three-shift operations.	Program will continue to monitor the Assembly, Test, and Launch Operations team's performance and assess potential mitigations and corrective actions as possible.

Software variances have grown due to higher than expected costs for testing and verification.	Continue to monitor progress.
The crew module engineering effort has experienced delays due to mass, interface, and abort loads challenges. These required further unplanned design studies and, consequently, delayed drawing releases. Late drawing releases led to delays in hardware fabrication/production.	Reducing overall staff volume and especially overtime labor, and revising the skill mix ratio to lower overall average labor rates and stay under plan. Possibly conduct process improvement analyses to increase cost savings through increased efficiencies.

Source: GAO presentation of NASA data. | GAO-16-620

Orion Program Lacks a Foundational Baseline to Reliably Measure Cost and Schedule Performance

Sound cost and schedule estimates are needed at the outset of complex programs to provide decision makers with a clear understanding of the cost risk inherent in the program, the cost of alternatives within the program, and the information to make resource allocation decisions. They are also vital tools in managing the types of risks that the Orion program is experiencing, as they provide management with critical cost-risk information to improve the control of resources in the present and the future as well as to provide insight into the impact of program changes on the program's budget, according to NASA's own cost estimating handbook. The Orion program did not conform to best practices when it developed the cost estimate and schedule estimate it used to inform the JCL calculations that led to the program's cost and schedule baselines. As a result, decision makers have reduced insight into program performance and do not have a foundational baseline upon which to make decisions. The Orion program did not meet or substantially meet a number of best practices for both the cost and schedule estimates, which support the program's committed launch readiness date for EM-2 of April 2023 and cost of $11.3 billion. Specifically, the program's cost estimate only met or substantially met 7 of 20 best practices and its schedule estimate only met or substantially met 1 of 8 best practices. As such, they do not fully reflect the characteristics of quality cost or schedule estimates and neither estimate can be considered reliable. The SRB had similar concerns with the program's estimate. The SRB required the program to perform additional analysis due to concern that the program was relying too heavily on contractor analysis, and found that the program would likely not meet its committed launch readiness date or cost.

Cost and Schedule Estimates Used to Inform Program Baselines Were Not Reliable According to Best Practices

The Orion program did not generally follow best practices in preparing its cost and schedule estimates, which were key inputs into the program's JCL process and baseline. In September 2015, NASA completed the Orion program's key decision point (KDP)-C review, where it established a cost baseline of $11.3 billion and a schedule baseline for an EM-2 launch readiness date of not later than April 2023 with a 70 percent

confidence level. Our review focused on the program's cost and schedule baseline as that forms the basis for NASA's external commitment to the Office of Management and Budget and the Congress, which is different from the program's prime contract period of performance noted above that extends through December 2020. In addition, the baseline commitment does not include a specific date for the launch readiness of EM-1. When we compared the cost and schedule estimates to the best practices found in our cost and schedule estimating guides, we deemed both estimates to be not reliable.[17] As a result, decision makers have reduced insight into program performance against cost projections as well as the program's ability to meet its cost commitments.

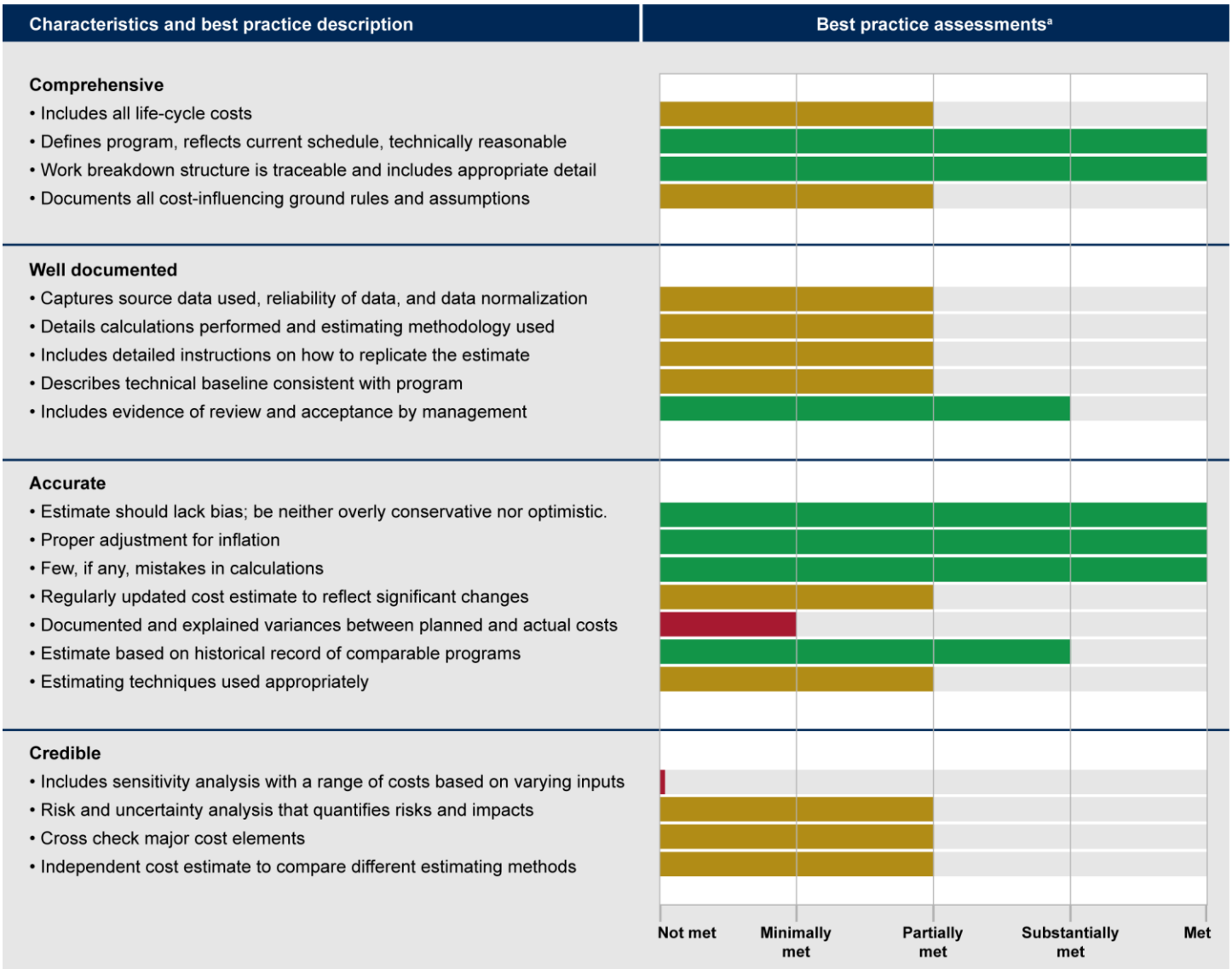
Cost Estimate

We found that the Orion program's cost estimate met or substantially met 7 of the 20 best practices that we have identified for preparing reliable cost estimates.[18] Without the necessary data, supporting documentation, and analysis, the cost estimate lacks reliability, which can leave the agency and decision makers without a clear sense of the program's expected cost. Such insight is needed as NASA develops its annual budgets for the program, makes trade-off decisions on where to concentrate resources, and to gauge progress, among other things. See figure 6.

[17]GAO-09-3SP and GAO-12-120G.

[18]Our research has identified 20 best practices that support the four characteristics of a high-quality, reliable cost estimate—comprehensive, well-documented, accurate, and credible—against which we compared the Orion program's cost estimate.

Figure 6: Summary Results of Orion's Cost Estimate Assessed against GAO's Best Practices Criteria



Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-16-620

[a]Not Met – NASA provided no evidence that satisfies any of the criterion, Minimally Met – NASA provided evidence that satisfies a small portion of the criterion, Partially Met – NASA provided evidence that satisfies about half of the criterion, Substantially Met – NASA provided evidence that satisfies a large portion of the criterion, and Met – NASA provided complete evidence that satisfies the entire criterion.

Comprehensive: The Orion cost estimate fully or substantially met 2 of the 4 best practices associated with a comprehensive estimate. The comprehensiveness of an estimate depends on how well it reflects the total scope of the program. It should include all program life-cycle costs, completely define the program, and include enough detail to ensure that cost elements are neither omitted nor double counted. In addition, all cost-influencing ground rules and assumptions must be detailed in supporting documents. While the program was clear that the estimate supported the Orion program through EM-2 plus 3 months, the program did not include the $4.7 billion spent under the Constellation program or funding planned for missions beyond EM-2, in accordance with our best practices to include all life-cycle costs. We previously recommended, in May 2014, that NASA include the costs incurred under Constellation into the baseline cost estimate and establish baselines for each additional capability that will encompass all life cycle costs, to include operations and sustainment for human exploration programs.[19] NASA partially concurred with our recommendation, stating that it would include cost estimates for each additional capability in its annual budget submission. However, reporting the costs via the budget process alone will not provide information about potential costs over the long-term because budget requests do not offer all the same information as life cycle cost estimates or serve the same purpose.

While budget estimates for missions beyond EM-2 are not yet public, notional budgets beyond EM-1 indicate that NASA expects to continue funding all three human exploration programs to at least current levels. Thus, the continuing costs for human exploration will likely remain a significant portion of NASA's budget in upcoming years. Without fully accounting for life-cycle costs, management will have difficulty planning program resource requirements and making informed decisions for the Orion program, the spaceflight portfolio as a whole, and how decisions could affect other missions, including science missions.

In addition, our assessment of the program's cost estimate showed that the estimate reflected technical changes to the vehicle and that the program's work breakdown structure—which defines in detail the work

[19]GAO, *NASA: Actions Needed to Improve Transparency and Assess Long-Term Affordability of Human Exploration Programs*, GAO-14-385 (Washington, D.C.: May 8, 2014).

necessary to accomplish a project's objectives, including activities both the program and the contractors are to perform—contained all NASA and contractor activities and included the level of detail and definitions necessary. However, the estimate did not include concise documentation of formal ground rules and assumptions, which can profoundly impact cost if they are proven wrong. The program stated that rules and assumptions were discussed in briefings to management. However, the briefing provided to us does not include a comprehensive list of ground rules or any technical assumptions, but it does include schedules and time frames. While the briefing also includes some limited information on risk and uncertainty methodology assumptions, such as formulas for applying uncertainty on duration and cost estimates, this briefing discusses models earlier than the one used to support the baseline. Without clear documentation of what the rules and assumptions were when the estimate was created, reviewers and managers cannot be sure that the estimate is not overly optimistic or that it has a sound base.

Well documented: The cost estimate fully or substantially met only 1 of the 5 best practices associated with a well-documented estimate. A well-documented cost estimate includes support that shows how the estimate was created and allows for ease of replication and updating and is traceable to information sources. The program included source data for some of the contractor and historical data used to support its cost assumptions. However, the source data lacked support in many instances throughout the estimate, which calls the reliability of the data into question. Both the methodology used to perform the estimate and how it was developed were lacking in detail and would make replicating the work difficult for anyone unfamiliar with this estimate. In addition, the estimate does not link directly to the program's technical baseline, which is used to benchmark life-cycle costs and identify specific program and technical risks. Without a proper linkage to the technical baseline, the cost estimate will lack specific information regarding technical and program risks. Lastly, while the program did not provide support that management reviewed all underlying analysis, the program's estimate was signed by program and agency management, which indicates that management reviewed and accepted the results of that analysis.

Accurate: The program's cost estimate fully or substantially met 4 of the 7 best practices associated with an accurate estimate. An accurate cost estimate is neither overly conservative nor overly optimistic and is as free as possible from biases and errors, is regularly updated to always reflect the current status of the program, and uses estimating techniques appropriately. We found that the estimate was largely without bias,

properly adjusted costs for inflation, and did not include any arithmetic errors. However, program officials stated that they have no intention of updating the cost estimate used for the JCL, even though NASA policy states it should be periodically updated with actual data. NASA program officials have taken this position with our review of the JCL for the James Webb Space Telescope and have yet to provide updates for the Space Launch System cost estimate.[20] The cost estimate and risk analysis should be updated continually to include current risks faced by the program, such as the EM-1 avionics reuse risk noted above—with a potential $165 million cost impact.

Without an estimate updated with actual costs, such as those incurred due to realized technical risks or cost overruns by contractors, it will be difficult to analyze changes and will make future estimates more difficult. In addition, a non-updated estimate cannot provide decision makers with accurate information for assessing the impacts of alternative decisions. Separately, not updating the estimate reduces the usefulness of the Orion estimate as a point of comparison for future programs. Without knowing how well the Orion estimate predicted actual program costs, and with limited documentation of the methodology used to create the estimate, future programs will have difficulty following the methods used by the Orion program. Such a practice leaves future programs in the position of creating estimates with less historical knowledge and having to perform more of their own analysis than might otherwise be necessary. Further, by not updating the cost estimate for the Orion program, the agency risks making budget decisions without reliable data and with reduced insight into cost performance. Finally, when performing analysis, the program modified actual costs from the December 2014 flight test to extrapolate estimated costs, but the support for those cost modifications was not fully documented.

Credible: The estimate did not fully or substantially meet any of the 4 best practices associated with a credible cost estimate. A credible cost estimate should analyze sensitivity of outcomes to changes of assumptions, clearly identify the limitations of the estimate due to uncertainty or bias, and cross-check cost drivers. Such an estimate also requires independent cost estimating—performed by an outside group—

[20]GAO-13-4 and GAO-15-596.

that supports the estimate's results, which provides an unbiased test of the estimate. The program did not perform a sensitivity analysis, without which program management could not have had a full understanding of the implications of changing assumptions on the program's cost. The program performed uncertainty analysis and proposed a range of costs that was applied to individual cost elements, as well as additional analysis similar to cross-checking of estimate data. In addition, the SRB assigned to the program performed its own review of the program's estimates and came to its own conclusions based on the results of its analysis, as discussed below. However, the uncertainty values and the program's proposed cost ranges within the uncertainty analysis had very little supporting documentation. The purpose of cross-checking the estimate and developing a separate independent estimate is to validate and test the program's estimate for reasonableness. Cross-check analysis should use alternate methodologies to verify and validate costs. However, the additional analysis that was performed by the program followed SRB concerns that the program was relying too heavily on contractor-provided data, not in order to cross-check the initial estimating methodologies. Similarly, the program's SRB reviewed the cost estimate and called into question the program's conclusions, but was not an independently created cost estimate that validated the original.

Schedule Estimate

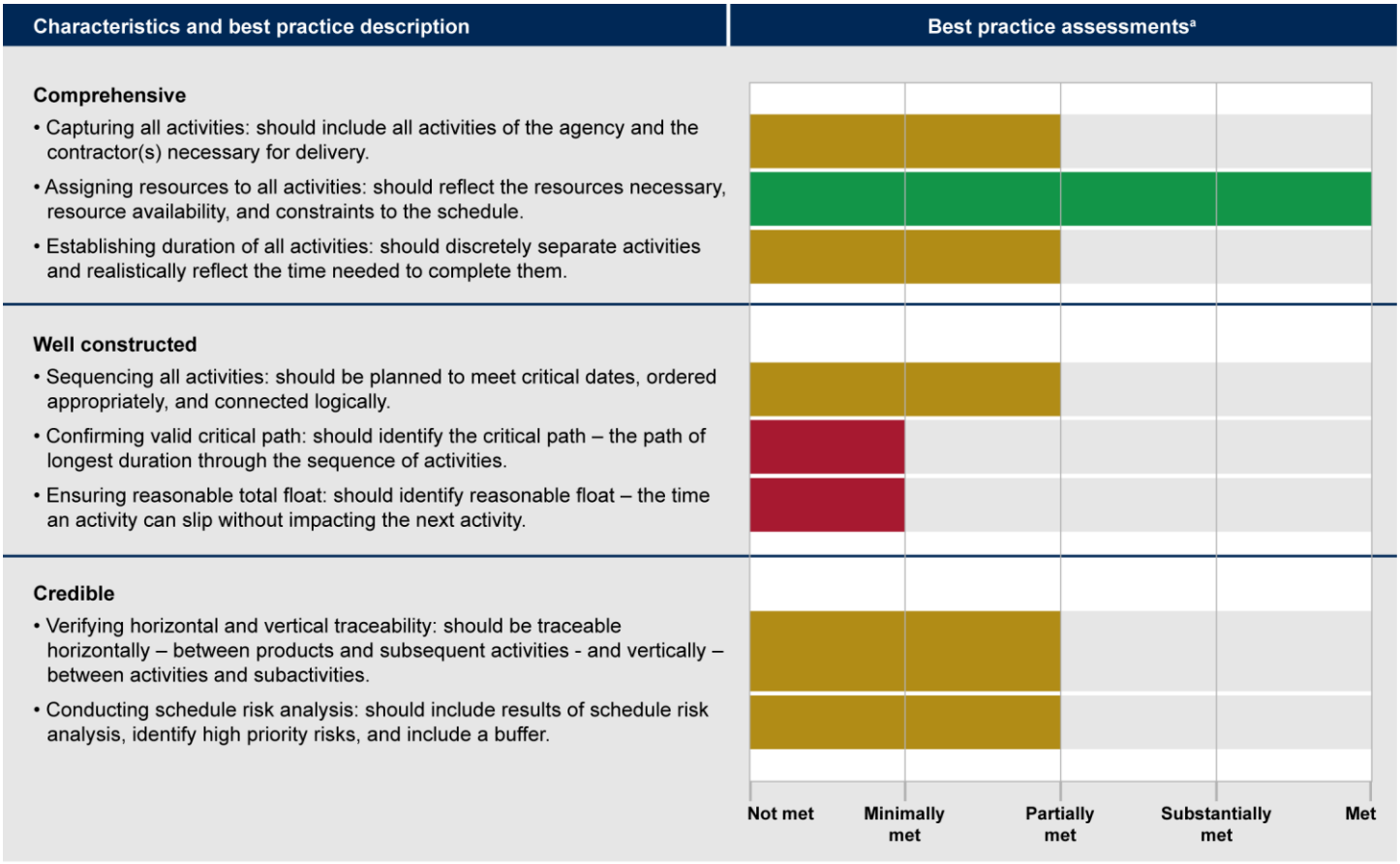
We found that the program's schedule estimate was not reliable based on schedule estimating best practices, which calls into question the ability of the program to meet its schedule baseline. A reliable schedule is a means by which to gauge progress, identify potential problems—such as the potential effect of realized risks—and is a vehicle for developing a time-phased budget baseline. For example, without a reliable schedule, the Orion program is not well positioned to understand the potential effect of delays associated with the late delivery of the European Service Module as described above.

For this review, 8 of the 10 schedule best practices outlined in our schedule guidance were applicable to the summary schedule—a condensed version of the program's integrated master schedule—created and used by the program to support the JCL.[21] We did not assess 2 best

[21]Our schedule guidance identifies 10 best practices that support four characteristics of a high-quality, reliable schedule estimate. We compared the Orion program's schedule estimate against 8 best practices across three characteristics—comprehensive, well-constructed, and credible; GAO-12-120G.

practices associated with the controlled characteristic of schedule estimating as those best practices would apply to a schedule used to track against a baseline. We found that the Orion program's schedule estimate for development through EM-2 fully or substantially met 1 of 8 best practices for preparing reliable schedule estimates. See figure 7.

Figure 7: Summary Results of Orion's Schedule Estimate Assessed against GAO's Best Practices Criteria



Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-16-620

[a]Not Met - NASA provided no evidence that satisfies any of the criterion, Minimally Met – NASA provided evidence that satisfies a small portion of the criterion, Partially Met – NASA provided evidence that satisfies about half of the criterion, Substantially Met – NASA provided evidence that satisfies a large portion of the criterion, and Met – NASA provided complete evidence that satisfies the entire criterion.

Comprehensive: The Orion schedule estimate fully or substantially met only 1 of the 3 best practices associated with a comprehensive estimate. The comprehensiveness of a schedule estimate depends on whether all government and contractor activities are included as well as the level of detailed resource and duration data assigned to those activities. The program properly linked activities to the work breakdown structure and assigned cost resources to activities; however, some activities lack explanation. We found that when establishing the duration or length of activities within the schedule estimate, the program often used actual data from the December 2014 flight test to establish activity durations in accordance with best practices. In some cases, estimators modified the durations of activities from the flight test based on assumptions and uncertainty surrounding these activities. However, no justification for the changes in duration was provided, which reduces confidence in the result. Long-duration activities in the schedule were created by combining many shorter-duration activities that had little flexibility. However, some activities were of an unreasonable duration; for example, we found activities compressed and combined to the point that 68 critical activities had durations of 585 days or longer. Program officials stated that the summary schedule used for the JCL contained long-duration activities that mirrored the planning packages of the program's integrated master schedule. However, a summary schedule that is overly condensed will not adequately convey the effort necessary for long-duration activities, the risks associated with those activities, or how total float—the amount of time activities can be delayed before they impact key program milestones—is distributed among key activities and milestones.

Well constructed: Orion's schedule estimate did not fully or substantially meet any of the 3 best practices associated with a well-constructed estimate. A well-constructed schedule estimate depends on logically sequenced activities showing the connections between them, a valid critical path that identifies activities driving the schedule, and an accurate account of total float that indicates schedule flexibility. The program did sequence the activities using straightforward logic between activities in most cases. However, nearly one-third of all activities were missing logic in that they were not linked to either a preceding or following activity. Program officials stated that a number of activities were missing predecessor activities because the program was already underway in 2012. This accounts for some, but not all, of the missing activities. Proper schedule logic requires clear connections between activities, without which schedule impacts—for example, delays—cannot be tracked through the entire schedule. We also found that the schedule did not clearly convey a valid critical path, which is the path of longest duration

through the sequence of activities leading to program completion, and did not project a reasonable amount of total float. Without these details it is difficult to see true project status and thus properly assess potential risks and opportunities in order to meet key milestones.

Credible: The program's schedule estimate did not fully or substantially meet either of the 2 best practices associated with a credible estimate. A credible schedule estimate is both horizontally traceable—that is, it reflects the necessary order of events to achieve outcomes—and vertically traceable—schedule data align between different levels of the schedule. In addition, a credible estimate requires a robust analysis of the risks associated with the schedule to identify high priority risks and appropriate levels of schedule contingency or reserve. The program's schedule estimate had some horizontal and vertical traceability, but it was not clear how the content and logic was validated and there were logic issues that impact the sequence of activities. For example, the schedule did not clearly convey a valid critical path and did not project a reasonable amount of total float. In order for a JCL to be valid, it must start with a schedule that meets best practices. The analyst needs to be confident that the schedule will automatically calculate the correct dates and critical paths when the activity durations change, as they do thousands of times during a simulation. As noted above, with the schedule's inability to indicate a valid critical path or reasonable amounts of total float, it is difficult to properly assess the effects of potential risks and opportunities. In addition, the lack of proper, adequate documentation calls the estimate's credibility into question. Further, missing logic decreases insight into how activities are connected to one another and obfuscates the impact of realized risks on the program's schedule.

We found that the Orion program's cost and schedule estimates used to support its JCL were not reliable. The result of our assessment is similar to the results we found for both the SLS and JWST programs. Overall, our analysis of the cost and schedule estimates that the Orion program used to support its JCL and cost and schedule baselines shows that both estimates lacked supporting documentation, supporting analysis, and that the Orion program does not plan to update the estimates—which reduces their usefulness for this and other programs. Program officials told us that the program has increased its cost and schedule analysis capability to include monthly cost, schedule, and risk analyses. While the results of the analyses are being used to manage the program internally, the data is not being reported to external stakeholders who manage the portfolio or to the Congress. Lacking these types of support leaves gaps in the credibility and reliability of the program's estimates. Such gaps, in turn,

leave decision makers in the position of deciding program and agency budgets without a foundational baseline that details what a program needs to successfully meet deadlines.

Standing Review Board Findings for Commitment Baseline

The SRB for Orion found issues with the program's cost and schedule estimates and with the results of the program's JCL. The SRB held a review of Orion leading into the program's KDP-C in September 2015 and communicated its concerns to the program and the agency prior to the establishment of Orion's cost and schedule baselines. The program and NASA management considered the SRB's findings and recommendations; however, those recommendations are not binding and final cost and schedule decisions rest with the NASA Administrator and Associate Administrator. The SRB called into question the program's cost and schedule estimates that fed into the program's JCL and found some of the same issues we highlight above. For example, the SRB had significant concerns that the program's cost estimate lacked support, that the program's summary schedule had faulty or missing logic, and the program's reported critical path did not have a solid basis. In addition, the SRB was concerned that the program was relying too heavily on contractor analysis and believed that the program should perform additional analysis. Further, the SRB also found that the program's JCL did not properly account for the costs of deferring work. In addition to its findings with regard to the program's cost and schedule estimates, according to the SRB, the SRB made adjustments to the program's JCL model by adjusting some of the program's risks and uncertainties. Specifically, in the SRB's judgment, the program underestimated risks associated with software development, reusing hardware from EM-1 in future tests, and testing for the launch abort system, among other risks. When the SRB applied what it deemed appropriate program risks and impacts to the JCL, they found that the program would likely need an additional $300 million and 6 months beyond the April 2023 date that the agency would later adopt as the program's committed baseline.

NASA and the Orion Program Are Making Programmatic Decisions That Further Exacerbate Challenges for Executing Program

Since the Orion program's baseline was set as part of its September 2015 KDP-C, NASA has managed to its internal schedule for completing development and production of the vehicle, which is aggressive and may exacerbate delays and lead to cost overruns in the program. The Orion program entered into an agreement with NASA management to work towards a more aggressive internal schedule than it committed to with a confidence level below what NASA policy requires, which means that NASA is accepting higher cost and schedule risk associated with executing this schedule. Working toward a more aggressive internal goal is not a bad practice; however, increasing cost and schedule risk to the program in order to pursue such a goal may not be a beneficial strategy to the program in the long term. To stay on the aggressive internal schedule, the agency is counting on receiving higher appropriated funds than what it plans to request, which may not be realistic in a constrained budget environment. Compounding this decision is that NASA and the Orion program have also made decisions that increase the risk of cost overruns and have led to work being deferred. The program has structured its cost and schedule reserves to be available primarily in the later years of the program life cycle. This has led the program to defer work when unexpected issues occur. This combined with the prime contractor carrying limited management reserves puts the program in the position of potentially facing a bow wave of deferred work that grows beyond what cost reserves and schedule margin can accommodate even when it is available in later years.

NASA and Program Agreed to Make Decisions Based on an Aggressive Internal Schedule, but Funding Requests Do Not Align with Schedule

NASA and the Orion program have chosen to pursue a more aggressive internal cost and schedule goal than its committed baseline set in September 2015 with a lower confidence level of meeting the cost and schedule targets. The Orion program's internal goal for EM-2—contained in a management agreement with NASA—includes a cost of $10.8 billion with launch readiness in August 2021.[22] See table 2 below for a comparison of the program's internal goal with the committed cost and schedule baseline.

[22]We did not assess the reliability of the cost and schedule estimates that were used by the Orion program for the more aggressive internal goals.

Table 2: Orion Program's Committed Cost and Schedule Baseline and Internal Cost and Schedule Goal, with Associated Joint Confidence Levels

	Cost (dollars in billions)	Launch readiness date	Joint confidence level (percent)
Committed baseline	11.3	April 2023	70
Internal program goal	10.8	August 2021	40

Source: GAO presentation of NASA data. | GAO-16-620

Both the program and the agency agreed to the more aggressive internal goals despite its joint confidence level of only 40 percent; NASA policy states that funding for program internal goals shall be consistent with the agreement with management and in no case less than the equivalent of a 50 percent confidence level. Therefore, the program's cost and schedule is aggressive beyond agency policy, and may increase the risk that the program goes over budget and does not meet its schedule. Agency officials stated that NASA management agreed to let the program hold to this aggressive internal schedule because that allowed the program to continue execution of the plan already in place prior to confirmation and which was set out in the cost-plus-award-fee contract of the prime contractor on the program. While award fee incentivizes the contractor for excellence in the areas of cost, schedule, and technical performance, the government still assumes more of the cost risk on the contract. Further, the program's SRB found that the program has a low likelihood of meeting its more aggressive internal EM-2 schedule goal of launching in August 2021.[23]

The program is making decisions based on this aggressive internal goal; however, the agency's budget requests and the program's KDP-C documents show that the agency has repeatedly requested funding levels below the level estimated to meet the program's internal goal of August 2021. Instead, the agency plans to request funding at the level estimated to meet the program's commitment date of April 2023. As a result, NASA relies on the Congress to appropriate more funds than requested to stay on its internal Orion schedule. While the Congress provided NASA with

[23]GAO, *NASA: Assessments of Major Projects*, GAO-16-309SP (Washington, D.C.: Mar. 30, 2016).

more funding than the agency requested for Orion in fiscal years 2012 through 2016, it may be unrealistic for NASA to expect additional funding each year given the constrained fiscal environment. Nevertheless, the program's internal goal would require appropriation levels of—on average—$75 million above the level of funding it plans to request to meet its committed baseline, which NASA identified in KDP-C documents, each year through at least fiscal year 2019.

Program Has Chosen a Reserve Structure That May Lead to a Bow Wave of Deferred Work

Complex development efforts like Orion must plan to address a myriad of risks and unforeseen technical challenges. To do this, programs reserve extra time in their schedules—which is referred to as schedule reserve—and extra money in their budgets—which is referred to as cost reserve. Schedule reserve is extra time in the program's overall schedule that is allocated to specific activities, elements, and major subsystems in the event there are delays or to address unforeseen risks. Cost reserves are additional funds that can be used to address unanticipated issues for any element or major subsystem during the development of a program. For example, cost reserves can be used to buy additional materials to replace a component or, if a program needs to preserve schedule reserve, cost reserves can be used to accelerate work by adding extra shifts to expedite manufacturing and save time. In addition to cost reserves held by the project manager, management reserves are funds held by the contractors that allow them to address cost increases throughout development. We have found that management reserves should contain 10 percent or more on the cost to complete a project and are used to address different issues.[24]

According to Orion program officials, the program has decided to employ most of its available appropriated funds to fund current work and has placed almost all of the funded schedule reserve—what NASA refers to as unallocated future expenses, or UFE—towards the end of the internal goal schedule, with very little available UFE in fiscal years 2016 and 2017. Specifically, almost all of the program's UFE is held after fiscal year 2017 with most of the UFE—78 percent—being held in fiscal years 2019 and 2020. Program officials stated that they decided on this strategy in

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

order to put most of their funds to work in any given year. However, because of this UFE structure, any time a significant technical issue arises, the program has had to reorder efforts or defer work. The program noted that the prime contractor is continuing to use deferrals to meet the budget. For example, the Orion program plans to defer approximately $40 million of planned crew module work for EM-2 in fiscal year 2016 due to contractor performance, needing budget to cover risks materializing, and opportunity for efficiencies not materializing.

Separately, in 2012, the program decided to defer a significant amount of the work on life-support systems to EM-2. The deferred components primarily include key life support systems like environmental control, communication systems, and flight software that will be necessary for crew and piloting support. According to program officials, the program made the decision early in development to defer these key crew life support systems to EM-2 based on annual funding constraints. See table 3 for examples of key life support systems deferred from EM-1 to EM-2.

Table 3: Examples of Systems Deferred from Exploration Mission-1 to Exploration Mission-2

Environmental control and life-support systems	**Communication and tracking**
Air revitalization	Emergency communications
Fire detection and suppression	Recovery communications
Full crew module pressure control	Audio system
Waste management	
Liquid cooling garment	
Crew systems and flight crew equipment	**Exploration Mission-2 flight software**
Suits	Crew and piloting support
Food system	
OASIS stowage	
Launch abort system	
Active launch abort system	

Source: GAO presentation of NASA data. | GAO-16-620

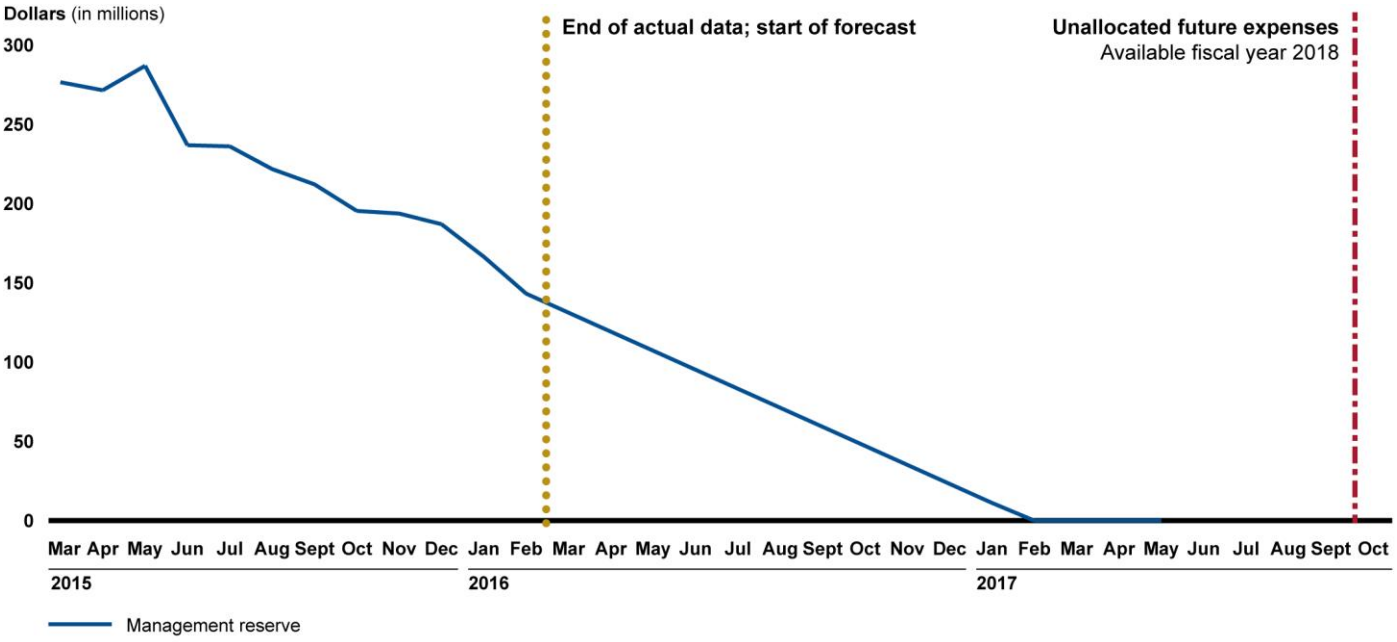
Waiting to fly these key systems for the first time when crew will be dependent upon them increases risk to the program. It also makes EM-1 a less representative test flight for all of the capsule's systems that will be required for the EM-2 mission. The program's SRB also raised concerns about deferring these systems, stating that deferral of these key life support elements from EM-1 to EM-2 raised cost and schedule risks. The SRB added that EM-1 was developed to be a test flight of the EM-2

vehicle, but budget reductions continue to erode the value of that plan. Additionally, in January 2016, the Aerospace Safety Advisory Panel expressed concern about the potential impacts of managing to an aggressive schedule—such as the program's internal schedule. In the report, the panel stated that "financial and perceived schedule pressures are impacting safety and design considerations" across the enterprise, and focused attention on the risk inherent in not testing crucial systems before flying a crewed mission.[25]

The lack of available UFE is further compounded by the program's prime contractor only carrying approximately 4 percent in management reserves—funds held by the contractor that allow it to address cost increases throughout development—based on work remaining. Contractor officials told us that they prefer to carry 10 percent in management reserves on their programs as a general goal, though the actual level varies from program to program at any point in time, but the program's UFE is planned to be available as management reserves are being used up. However, we found that the contractor's use of management reserve has been accelerating in recent months and—at its current 12-month average spend rate—the contractor would exhaust its cost management reserves by February 2017, about 8 months before significant amounts of UFE are planned to be available in fiscal year 2018. See figure 8.

[25]NASA Aerospace Safety Advisory Panel, "Annual Report for 2015." The Aerospace Safety Advisory Panel evaluates NASA's safety performance and advises the agency on ways to improve that performance based on direct observation of NASA operations and decision-making.

Figure 8: Orion Prime Contractor Cost Management Reserve from March 2015 to February 2016 with Forecast of Spending Based on Historical Averages



Source: GAO analysis of National Aeronautics and Space Administration (NASA) data. | GAO-16-620

Program officials told us that the contractor's work from March 2015 to February 2016 is not representative of the type of work that they will be performing moving forward and, as a result, stated that they expect the contractor's usage of management reserves to level off as the program enters integration and test based on the trends experienced prior to the December 2014 flight test. However, we remain concerned that if the recent acceleration of reserves usage continues, the potential absence of contractor management reserve could lead the program to defer more work to future years and potentially encumber much of fiscal year 2018 UFE once it becomes available. The combination of back-loaded UFE and lack of management reserve has already resulted in the program performing less work than it has planned for, and could result in a bow wave of deferred work that grows beyond what cost reserves and schedule margin can accommodate even when it is available as of 2018. The SRB also found that essentially all of the UFE is held between the planned launch readiness date and the committed launch readiness date, inhibiting early risk mitigation by the program.

Program officials stated that the deferral of work is consistent with the program's strategy to develop a complex spacecraft with a flat funding profile and an aggressive schedule, and that they track the deferral of work in order to provide the program manager a monthly update of pressure being placed on schedule margin. They have not, however, performed a formal analysis to understand the impact that delaying work might have on the available UFE since the KDP-C process, where the amount of necessary UFE was determined. According to our cost estimating guide, the ability to act quickly to resolve program problems depends on having an early view of what is causing them.[26] Access to accurate progress assessments gives program management a better picture of program status and leads to better decisions. Without any formal analysis, program management may not have a complete understanding of how the decisions to defer work in the short-term will affect the longer-term execution of the program.

Given how UFE is being utilized, the Orion program may find itself in a similar situation to that experienced by the Constellation JWST programs, which had minimal cost reserves in early years to handle technical challenges that manifested and forced the programs to defer work. In 2009, we found that the Constellation program had gaps in its business case that included a poorly phased funding plan that increased the risk of funding shortfalls and resulted in planned work not being completed to support schedules and milestones.[27] A 2010 independent panel found that JWST continually deferred work to future years to stay within its annual budget commitments, a practice that was known and condoned by NASA management.[28] The panel added that deferred work could potentially result in overall JWST program costs doubling or tripling due to its impact on other work and can lead to a cascading effect wherein the cost of delayed activities further encumbers the reserves available to the project in later years. Further, the panel noted that the inefficiencies created when deferring already planned work led to escalating JWST cost growth and continued schedule erosion. Because, in part, of this practice

[26]GAO-09-3SP.

[27]GAO-09-844.

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

of deferring work repeatedly, the JWST program underwent a replan that resulted in a $3.6 billion cost increase and a 52-month launch delay.

Conclusions

Human spaceflight and exploration beyond low-Earth orbit are goals that NASA and the Congress have supported as a significant part of the agency's portfolio, and decision makers must be kept informed of the true cost and schedule of NASA's human spaceflight programs in order for the programs to be positioned to succeed. NASA established a cost and schedule baseline for the Orion program in 2015, but the estimates used to inform those baselines are not reliable based on not meeting best practices because of a lack of documentation, the absence of a separate independent cost estimate to validate the results, and a schedule that has logic errors, among other issues. As a result, neither NASA nor the Congress has the necessary insight into the program's expected cost and schedule. Such insight is necessary to provide program and agency officials with a more informed basis for decision making and to provide the Congress with more accurate information to support the appropriation process. When the Congress lacks proper insight into the program's cost and schedule, it is put in the position of making decisions without the insight necessary to know whether or not those decisions are suitable for the execution of the program.

Further, the program faces a number of risks that could impact its cost and launch readiness availability, in addition to the pressure of maintaining an internal schedule. Programmatic risks are being driven by decisions made at the program level that are seemingly focused on achieving schedule milestones, even though the agency continues to request funding that does not support that schedule. Further, for EM-2, the program may spend more to attempt to reach its internal launch readiness goal of August 2021—which already has a potentially large cost overrun—than it planned to achieve the later commitment date of April 2023. Managing toward an internal schedule can be a good strategy if the more aggressive plan is based upon reliable estimates, the program has sufficient and properly phased contingency reserves in the event development issues arise, and decisions are not based upon prioritizing schedule to the detriment of sound development practices. To effectively manage to its internal schedule, however, the program needs to ensure that it does not incentivize short-sighted decisions in pursuit of its aggressive goal and both the program and its prime contractor need to have an understanding of how their schedule and cost reserves may be affected by deferred work. Without this knowledge, neither the Congress nor NASA management can reliably know how the program's decisions to

pursue their schedule may impact the program in its later years, including that a significant number of technical risks are being pushed to EM-2.

Recommendations for Executive Action

We recommend that the NASA Administrator take the following two actions:

To provide the Congress and NASA a reliable estimate of program cost and schedule that are useful to support management and stakeholder decisions, direct the Orion program to perform an updated JCL analysis including updating cost and schedule estimates in adherence with cost and schedule estimating best practices.

To have a full understanding of the cost, schedule, and safety impact of deferring work, direct the Orion program to perform an analysis on the cost of deferred work in relation to levels of management reserves and unallocated future expenses and actual contractor performance, and report the results of that analysis to NASA management.

Agency Comments and Our Evaluation

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

In responding to a draft of our report, NASA partially concurred with one recommendation and concurred with a second recommendation. NASA partially concurred with our recommendation to update the JCL analysis, including updating cost and schedule estimates for the Orion program in adherence with best practices. In response to this recommendation, NASA stated that the agency reviewed, in detail, the Orion integrated cost/schedule and risk analysis methodology during the KDP-C decision process and determined the rigor to be a sufficient basis for the agency commitments. Further, NASA noted that the program's performance metrics are reviewed regularly. If the metrics were to show a significant deviation from the plan, then NASA would initiate a formal rebaselining process, which would include a re-assessment of the fundamental program assumptions and associated recalculation of the JCL. Until that time though, NASA stated that performing a new JCL is not warranted.

We still contend that NASA should update its JCL analysis that informed its baseline because we found that the cost and schedule estimates underlying those baselines are not reliable as they did not conform to best practices. For example, the program did not conduct a cross-check of its

cost estimate, nor did it ensure that source data and estimating techniques were sufficiently documented so that they could be reviewed and replicated. Further, the program's schedule estimate had significant logic faults and did not convey a valid critical path. Thus, we continue to believe that NASA will be well-served by updating the Orion program's cost and schedule estimates to adhere to best practices and to perform an updated JCL for the program. With respect to NASA's statement in its response that it "is concerned that the GAO may not have consistently evaluated all available data in the baseline program when assessing the reliability of Orion's cost and schedule estimates," we met multiple times with the program, reviewed extensive documentation, and provided the program with two opportunities to provide additional documentation based upon its review of preliminary results of our analysis. We made changes to our analysis based on additional information provided to us by the program following its review of the preliminary results and believe this report represents a fair and accurate assessment of the extent to which the program met best practices.

NASA concurred with our recommendation to have the program perform an analysis of the cost of deferred work as compared to available cost reserves—contractor-held management reserves and program-held unallocated future expenses—and contractor performance levels, and to report that analysis to agency management. NASA characterized its deferral of work to date as task-level deferrals, lasting only several months and not affecting major program milestones or the critical path, but agreed to include an analysis of how these deferrals affect budget reserves and program performance in future routine management reporting. Given the finite funds available each year and the low level of in-year cost reserves, we believe that until the results of such an analysis are available, it will be difficult to understand the impacts of this deferred work.

Finally, in its response to our recommendations, NASA officials made reference to a statement that we made in this report but did not include its full context. Specifically, NASA included the following statement in its response: "GAO also noted that NASA's management of schedule reserves on Orion is a viable approach to managing large human spaceflight programs. GAO noted that 'working toward a more aggressive internal goal is not a bad practice.'" We would like to clarify that the full context of the statement is that while we do not believe working toward a more aggressive internal goal is a bad practice, increasing cost and schedule risk to the program in order to pursue such a goal may not be a beneficial strategy to the program in the long term.

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

If you or your staff have any questions about 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 at listed in Appendix IV.

Cristina T. Chaplain
Director, Acquisition and Sourcing Management

Appendix I: Scope and Methodology

To assess the technical challenges for the National Aeronautics and Space Administration's (NASA) Orion Multi-Purpose Crew Vehicle (Orion) program and the extent to which those challenges may impact cost and schedule commitments we obtained and reviewed monthly and quarterly reports and the risks tracked in both the program's and the prime contractor's risk management systems, which list the top program risks and their potential cost and schedule impacts. We interviewed program and prime contractor officials with knowledge of technical risks the program faces, asked how the program is monitoring those risks, what the technical challenges and potential impacts are, and how they are planning to mitigate those risks. We requested interviews with officials from the European Space Agency responsible for producing the European Service Module in order to better understand their partnership with NASA and their program management for integrating the European Service Module; however, we were referred to NASA for information regarding work on the European Service Module. We obtained and analyzed contractor cost and schedule monthly reports—or earned value management (EVM) data—for the program's prime contractor from May 2014 through February 2016, to determine the extent to which the data were consistent with EVM best practices identified in GAO's Cost Estimating and Assessment Guide.[1] We assessed the reliability of the NASA EVM system for the Orion program and analyzed the EVM data in order to understand contractor cost and schedule trends shown by the data. We provided preliminary findings to the Orion program and received written responses. We only used EVM data from the prime contractor.

To assess the reliability of NASA's Orion program's cost and schedule estimates, we determined the extent to which the estimates were consistent with best practices as identified in GAO's Cost Estimating and Assessment and Schedule Assessment guides.[2] We examined documents supporting the cost and schedule estimates, such as detailed spreadsheets that contain cost, schedule, and risk information and the timing and availability of program funding and reserves, as well as relevant NASA policy. We did not assess the schedule estimate against

[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).

[2]GAO, GAO-09-3SP and *GAO Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-12-120G (Washington, D.C.: May 30, 2012).

the controlled criteria as the schedule estimate was completed to support Joint Cost and Schedule Confidence Level (JCL) calculations and the controlled criteria deals, in part, with updating the schedule periodically. A JCL, however, is not designed to be used as an updating tool. We met with program personnel responsible for creating the cost and schedule estimates to understand the processes used by the program, to clarify information, and to allow the program to provide additional documentation to support their position. We met with members of the program's standing review board, reviewed their report on the program's estimates and JCL, and determined the extent to which the Orion program addressed any concerns the reviewers raised. In addition, we met with program and agency officials to discuss the baseline cost and schedule estimates, potential program schedule changes, and the program's cost and schedule reserve postures, among other issues. Finally, we reviewed NASA acquisition policy to determine if Orion program was in compliance with respect to confidence level of cost and schedule baseline estimates and internal management agreements.

To assess the extent to which agency and program programmatic decisions affect cost and schedule risks, we obtained and reviewed copies of program documentation, including monthly and quarterly reports. To assess the availability of the program's cost and schedule reserves, we analyzed its budget documentation and the prime contractor's EVM data for management reserve amounts. We interviewed NASA and program officials with technical and programmatic knowledge of the program's formulation and development, program management and program budget specialists to discuss the program's budget and reserve postures, and prime contractor officials to discuss the management reserve being held by them and how these reserves were used to mitigate known risks. We interviewed members of the program's standing review board about technical, cost, and schedule risks to the program and reviewed a report from NASA's Aerospace Safety Advisory Panel in carrying out analyses of risks.[3]

Our work was performed primarily at NASA headquarters in Washington, D.C., and Johnson Space Center in Houston, Texas. We also visited

[3]NASA Aerospace Safety Advisory Panel, *Annual Report for 2015* (Washington, D.C: Jan. 13, 2016).

Marshall Space Flight Center in Huntsville, Alabama; Glenn Research Center in Cleveland, Ohio; Plum Brook Station in Sandusky, Ohio; and Lockheed Martin Space Systems Company in Houston, Texas.

We conducted this performance audit from September 2015 to July 2016 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Earned Value Management Data Reliability

After reviewing documentation the Orion program office submitted for its earned value management (EVM) system, and reviewing relevant sources, we determined that the National Aeronautics and Space Administration (NASA) earned value data substantially met all 3 best practices that we assessed, as shown in table 4. EVM data are considered reliable if the overall assessment ratings for each of the 3 characteristics are met or substantially met. If any of the characteristics are not met, minimally met, or partially met, then the EVM data cannot be considered reliable.

Table 4: Summary Assessment of the Orion Program's EVM Data and Practices Compared to Best Practices

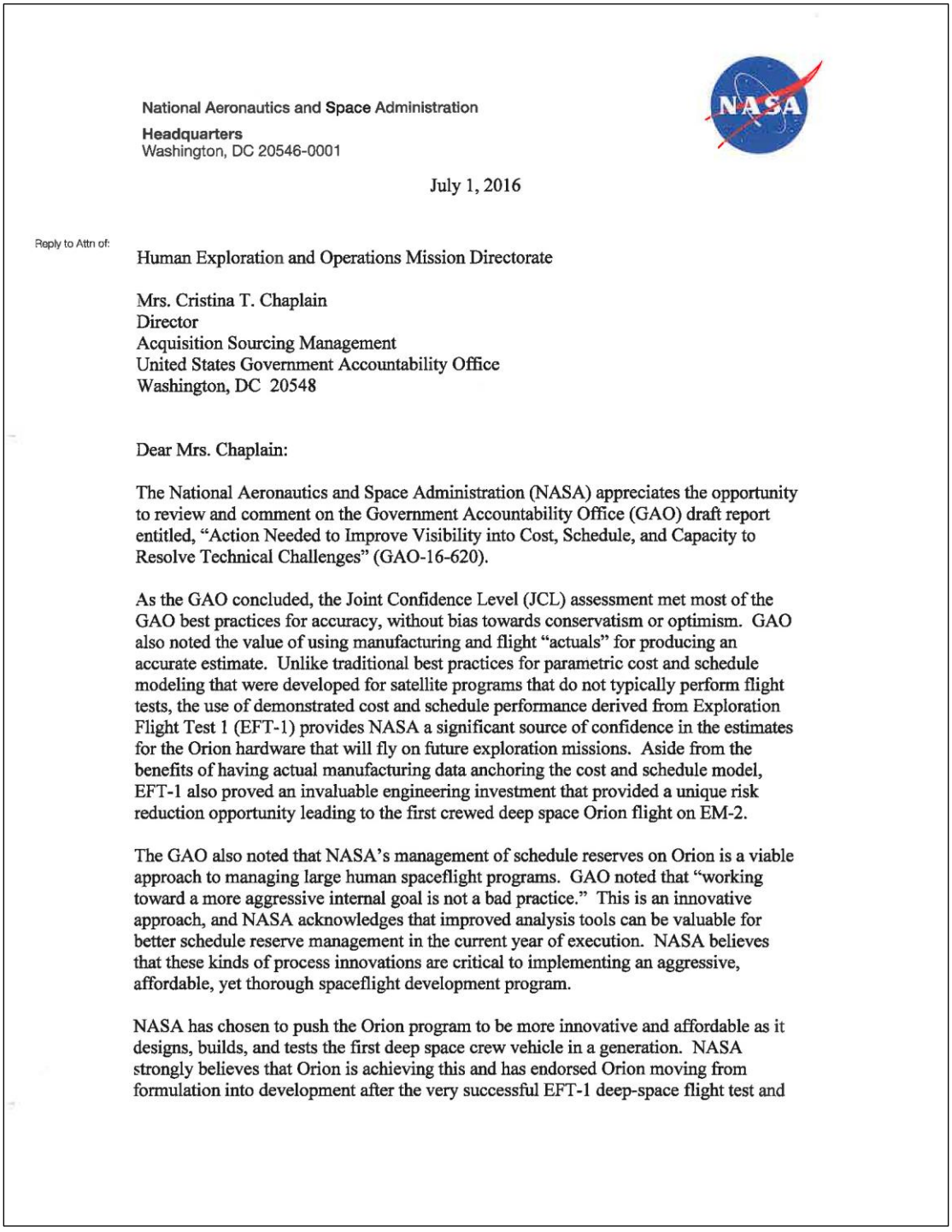
Characteristic	Overall assessment[a]	Best practice	Assessment[b]
Establish a comprehensive EVM system:	Substantially Met	The program has a certified EVM system.	Substantially Met
		An Integrated Baseline Review (IBR) was conducted to ensure the performance measurement baseline captures all of the work.	Met
		The schedule reflects the work breakdown structure, the logical sequencing of activities, and the necessary resources.	Partially Met
		EVM surveillance is being performed.	Met
Ensure that the data resulting from the EVM system are reliable:	Substantially Met	EVM data do not contain any anomalies.	Partially Met
		EVM data are consistent among various reporting formats.	Substantially Met
		Estimate at completion is realistic.	Substantially Met
Ensure that the program management team is using earned value data for decision-making purposes:	Substantially Met	EVM data, including cost and schedule variances, are reviewed on a regular basis.	Substantially Met
		Management uses EVM data to develop corrective action plans.	Met
		The performance measurement baseline is updated to reflect changes.	Partially Met

Source: GAO analysis of NASA data. | GAO-16-620

[a]We determined the overall assessment rating by assigning each individual rating a number: Not Met = 1, Minimally Met = 2, Partially Met =3, Substantially Met = 4, and Met = 5. Then, we took the average of the individual best practice assessment ratings to determine the overall rating for each of the three 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.

[b]Not Met – NASA provided no evidence that satisfies any of the criterion, Minimally Met – NASA provided evidence that satisfies a small portion of the criterion, Partially Met – NASA provided evidence that satisfies about half of the criterion, Substantially Met – NASA provided evidence that satisfies a large portion of the criterion, and Met – NASA provided complete evidence that satisfies the entire criterion.

Appendix III: Comments from the National Aeronautics and Space Administration



National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

July 1, 2016

Reply to Attn of:

Human Exploration and Operations Mission Directorate

Mrs. Cristina T. Chaplain
Director
Acquisition Sourcing Management
United States Government Accountability Office
Washington, DC 20548

Dear Mrs. Chaplain:

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to review and comment on the Government Accountability Office (GAO) draft report entitled, "Action Needed to Improve Visibility into Cost, Schedule, and Capacity to Resolve Technical Challenges" (GAO-16-620).

As the GAO concluded, the Joint Confidence Level (JCL) assessment met most of the GAO best practices for accuracy, without bias towards conservatism or optimism. GAO also noted the value of using manufacturing and flight "actuals" for producing an accurate estimate. Unlike traditional best practices for parametric cost and schedule modeling that were developed for satellite programs that do not typically perform flight tests, the use of demonstrated cost and schedule performance derived from Exploration Flight Test 1 (EFT-1) provides NASA a significant source of confidence in the estimates for the Orion hardware that will fly on future exploration missions. Aside from the benefits of having actual manufacturing data anchoring the cost and schedule model, EFT-1 also proved an invaluable engineering investment that provided a unique risk reduction opportunity leading to the first crewed deep space Orion flight on EM-2.

The GAO also noted that NASA's management of schedule reserves on Orion is a viable approach to managing large human spaceflight programs. GAO noted that "working toward a more aggressive internal goal is not a bad practice." This is an innovative approach, and NASA acknowledges that improved analysis tools can be valuable for better schedule reserve management in the current year of execution. NASA believes that these kinds of process innovations are critical to implementing an aggressive, affordable, yet thorough spaceflight development program.

NASA has chosen to push the Orion program to be more innovative and affordable as it designs, builds, and tests the first deep space crew vehicle in a generation. NASA strongly believes that Orion is achieving this and has endorsed Orion moving from formulation into development after the very successful EFT-1 deep-space flight test and

Key Decision Point C (KDP-C) review. Orion's flight test provided NASA with unprecedented set of design, production, and demonstrated flight data, on things like supplier performance, cost, delivery, and risk. This highly successful accomplishment provides actual experience that offers a basis that is more accurate than traditional cost estimating. NASA is concerned that the GAO may not have consistently evaluated all available data in the baseline program when assessing the reliability of Orion's cost and schedule estimates.

In accordance with the NASA Authorization Act of 2010 to "take appropriate actions to ensure timely and cost-effective development" of the Multi-Purpose Crew Vehicle (MPCV) including the "facilitation of contractor efficiencies, and the streamlining of contract and procurement requirements," NASA formulated the Orion Program with the expectation that aggressive and affordable management approaches would be employed. Many traditional management techniques have been adapted to provide the essential planning and situational awareness needed to run a complex spacecraft development program, while simplifying and streamlining those techniques to achieve the cost reductions which the Congress directed. As GAO noted, employing such an innovative and aggressive approach to achieving difficult objectives inevitably and unavoidably involves accepting certain levels of technical and programmatic risk over traditional approaches.

Orion continues to make extraordinary progress toward meeting the national objective of human exploration of the solar system. The excellent schedule performance has been achieved while the Orion development team has successfully overcome many difficult development challenges. One recent example is the delivery of a mass optimized EM-1 Crew Module structure on the original schedule that had been established over 24 months prior despite encountering major manufacturing challenges.

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

Recommendation 1: To provide the Congress and NASA a reliable estimate of program cost and schedule that are useful to support management and stakeholder decisions, direct the Orion program to perform an updated JCL analysis including updated cost and schedule estimates in adherence with cost and schedule estimating best practices.

Management's Response: Partially Concur. NASA's integrated suite of performance management tools and processes proved effective during the program execution leading to EFT-1 in December 2014. And now, the results of EFT-1 give Orion a detailed understanding of manufacturing against which to measure EM-1. Execution of the EM-1 and all future exploration missions in our multi-decadal program continues to demonstrate Orion cost and schedule estimates reliably inform Program Management and Agency decision processes. NASA has already further augmented the management process controls with performance monitoring against the formally established Agency cost and schedule commitments.

NASA remains on track to update all risk-based cost and schedule models, per standard Agency practice, as the natural dynamic of the program demands, and, at minimum, annually in support of the budget formulation process. The Agency reviewed, in detail, the Orion integrated cost/schedule and risk analysis methodology during the KDP-C decision process and determined the rigor and effectiveness of the Orion management approach to be sufficient basis for the agency commitments. The Agency Program Management Council will again review updated Orion cost and schedule projections in the summer of 2016 to conclude the Critical Design Review (CDR) process in accordance with the formally approved CDR Plan.

NASA policy, as provided in the Agency's Cost Estimating Handbook, provides for the use of JCL as one of many tools Agency decision makers use to inform the setting of cost and schedule commitments at KDP-C in a program's life cycle. Once a program baseline is approved at KDP-C, the Agency utilizes a variety of performance metrics that employ data on actual development activities to assess how well the project is performing against its plan which are more accurate than a JCL. Orion's performance metrics (including earned value management, reserve posture, schedule performance, risk management, costing, and meeting technical milestones) are reviewed regularly at the program, enterprise, Directorate, and Agency level, with independent assessments conducted by the Standing Review Board during specified points in the program life cycle, including during periodic audits by the NASA Inspector General and GAO. Per established Agency practice, if these metrics were to show that a program's performance was deviating significantly from its plan, the program would go through the formal rebaselining process, including a re-assessment of the fundamental program assumptions and associated recalculation of the JCL. To date, as the GAO correctly noted, Orion continues to perform within the boundaries of the program cost and schedule commitment made at KDP-C. A recalculation of the JCL is, thus, not warranted; further, it would not be the best tool to gauge program progress and inform management and stakeholder decision-making. NASA does annually review Orion program progress and cost-to-complete as a part of the Agency budgeting process and will continue to do so.

Recommendation 2: To have a full understanding of the cost, schedule, and safety impact of deferring work, direct the Orion program to perform an analysis on the cost of deferred work in relation to levels of management reserves and unallocated future expenses and actual contractor performance and report the results of that analysis to NASA management.

Management's Response: Concur. In an evolving, multi-flight program such as Orion, the phasing of new capability additions over successive flight missions provides an important dimension of flexibility to optimize technical and funding implementation. NASA described, to the GAO, the critical flexibility that judicious deferral of work has in the aggressive program strategy the Agency has chosen to execute the Orion program within the annual funding constraints. The Agency reformulated Orion using incremental addition of selected crew-specific functions between EM-1 and EM-2 as a key enabler to the initial strategy. The EM-1 and EM-2 configurations are described in the program-controlled Vehicle Configuration Matrix, which NASA demonstrated has been extremely

stable since it was baselined. The Agency has confirmed that the program's cost and schedule estimates of all unique EM-2 functions are rigorous and complete and are included in all programmatic projections performed by Orion. NASA also described how task-level deferrals of work provides a management technique for adjusting priorities and redirecting resources to respond to issues while maintaining the level cost profile in the program plan. These task-level deferrals, typically of several months duration, do not impact major program milestones or the critical path and have proven to be an effective aggressive management technique. NASA will analyze these task deferrals and projected impacts on available budget reserves and program performance and will include these in future routine management reporting.

It is also important to note that NASA is developing a system that will be used for many decades beyond the initial flights on EM-1 and EM-2. NASA is investing in much more than just EM-1 and EM-2. Although EM-1 and EM-2 are critical near term milestones, these missions do not reflect the breadth of system being developed.

Once again, thank you for the opportunity to comment on this draft report. If you have any questions or require additional information, please contact Michelle Bascoe at (202) 358-1574.

Sincerely,

William H. Gerstenmaier
Associate Administrator
for Human Exploration and Operations

Appendix IV: GAO Contact and Staff Acknowledgments

GAO Contact

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Staff Acknowledgments

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