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NASA HUMAN SPACE EXPLORATION

Significant Investments in Future Capabilities Require Strengthened Management Oversight

GAO-21-105

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GAO Highlights

Highlights of GAO-21-105, a report to congressional committees

Why GAO Did This Study

NASA is pursuing an aggressive goal to return American astronauts to the surface of the Moon by the end of 2024. The success of NASA's plans hinges, in part, on two upcoming test flights. An uncrewed test flight and subsequent crewed test flight are intended to demonstrate the capability of a new launch vehicle, crew capsule, and ground systems.

The House Committee on Appropriations included a provision in its 2017 report for GAO to continue to review NASA's human space exploration programs. This is the latest in a series of GAO reports addressing this topic. This report assesses (1) the progress the programs are making towards the first test flight, known as Artemis I, with respect to schedule and cost, and (2) the extent to which NASA's human space exploration programs are positioned to support the planned Artemis flight schedule beyond Artemis I.

To do this work, GAO examined program cost and schedule reports, test plans, and contracts, and interviewed officials. GAO also assessed the extent to which the COVID-19 state of emergency has affected schedules for these programs.

What GAO Recommends

GAO is making two recommendations to NASA to establish baselines ahead of a key design review and improve internal reporting about capability upgrades for human space exploration programs beyond Artemis I. NASA concurred with the recommendations made in this report.

View GAO-21-105. For more information, contact William Russell at (202) 512-4841 or russellw@gao.gov.

What GAO Found

The National Aeronautics and Space Administration (NASA) again delayed the planned launch date for Artemis I, the first uncrewed test flight involving three closely related human spaceflight programs—the Orion crew vehicle, Space Launch System (SLS), and Exploration Ground Systems (EGS). Together, these programs aim to continue human space exploration beyond low-Earth orbit. The most recent delay, to November 2021, resulted in part from manufacturing challenges and represents a 36-month slip since NASA established a schedule to measure performance in 2014. This new launch date does not account for the effects of COVID-19. According to NASA officials, COVID-19 delays and schedule risks will place pressure on NASA's ability to achieve this launch date.

Development cost estimates for key programs also increased. The cost of the SLS program increased by 42.5 percent and the EGS program by 32.3 percent since 2014, for a combined increase of over $3 billion, bringing the total to $11.5 billion. NASA does not plan to complete revised estimates for Orion, which are tied to the second, crewed test flight (Artemis II) before spring 2021.

Key Parts of Space Launch System Ready for Testing at Stennis Space Center

Source: National Aeronautics and Space Administration/Stennis Space Center. | GAO-21-105

NASA awarded billions of dollars in development and production contracts to support flights beyond Artemis I, but the flight schedule has changed frequently due to a lack of clear requirements and time frames for planned capability upgrades. Limited NASA oversight also places efforts to plan and execute future flights at risk of adverse outcomes, such as increased costs or delays. For example, NASA is committed to establishing cost and schedule performance baselines for these efforts, but it plans to do so too late in the acquisition process to be useful as an oversight tool. In addition, senior leaders do not receive consistent and comprehensive information at quarterly briefings on future efforts, such as a program to begin developing a more powerful upper stage for SLS. This is because current updates provided to NASA management focus primarily on the more short-term Artemis I and II flights. This approach places billions of dollars at risk of insufficient NASA oversight.

Contents

Letter 1

Background 5
Significant Artemis I Delays and Cost Growth Place Pressure on the Schedule for Future Missions, and Complex Testing and Integration Remain 12
Uncertain Plans, Unproven Cost Assumptions, and Limited Oversight Place Future Artemis Missions at Increased Risk of Poor Outcomes 20
Conclusions 34
Recommendations for Executive Action 34
Agency Comments and Our Evaluation 35

Appendix I Comments from the National Aeronautics and Space Administration 36

Appendix II GAO Contact and Staff Acknowledgments 38

Tables

Table 1: Characteristics of Program Replans and Rebaselines 11
Table 2: Space Launch System and Exploration Ground Systems Program Development Cost and Schedule Baselines and Revised Estimates for Artemis I (cost in billions) 13
Table 3: Major Contracts across the Orion, Exploration Ground Systems, and Space Launch System Programs 25

Figures

Figure 1: Space Launch System and Orion Multi-Purpose Crew Vehicle Hardware 6
Figure 2: Mobile Launcher on the Crawler-Transporter outside the Vehicle Assembly Building at Kennedy Space Center 7
Figure 3: Proposed Schedule for First Three Artemis Missions 8
Figure 4: Space Launch System Planned Block Upgrades 9
Figure 5: NASA's Acquisition Life Cycle for Space Flight Programs 10
Figure 6: Recent Orion Program Test Events for Artemis I 16
Figure 7: Orion Spacecraft in the Thermal Vacuum Chamber at Plum Brook Station, Sandusky, Ohio 17

Figure 8: Space Launch System Core Stage in Stennis Space Center Test Stand 19

Abbreviations

CPAF	cost-plus-award-fee
CPIF	cost-plus-incentive-fee
COVID-19	Coronavirus Disease 2019
EGS	Exploration Ground Systems
ESD	Exploration Systems Development
ESM	European Service Module
EUS	Exploration Upper Stage
FAR	Federal Acquisition Regulation
FFP	firm-fixed-price
FPDS-NG	Federal Procurement Data System-Next Generation
ICPS	interim cryogenic propulsion stage
IDIQ	indefinite-delivery indefinite-quantity
KDP	key decision point
NASA	National Aeronautics and Space Administration
OIG	Office of Inspector General
OMB	Office of Management and Budget
OPOC	Orion Production and Operations Contract
Orion	Orion Multi-Purpose Crew Vehicle
SLS	Space Launch System
TLI	Trans Lunar Injection
UCA	undefinitized contract action

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December 15, 2020

The Honorable Jerry Moran
Chairman
The Honorable Jeanne Shaheen
Ranking Member
Subcommittee on Commerce, Justice, Science,
and Related Agencies
Committee on Appropriations
United States Senate

The Honorable José E. Serrano
Chairman
The Honorable Robert B. Aderholt
Ranking Member
Subcommittee on Commerce, Justice, Science,
and Related Agencies
Committee on Appropriations
House of Representatives

The National Aeronautics and Space Administration (NASA) is pursuing an aggressive goal to return American astronauts to the surface of the Moon by the end of 2024. In March 2019, the White House directed NASA to accelerate its plans for a lunar landing from its original goal of 2028. The success of this endeavor, known as Artemis III, hinges on successful completion of an uncrewed test flight—Artemis I—and a crewed test flight—Artemis II—to demonstrate the capability of a new launch vehicle, crew capsule, and associated ground systems. NASA is also planning for these systems to support six additional deep space missions through 2030, with more to follow. These systems include

- the Space Launch System (SLS), which is a vehicle to launch a crew capsule and cargo beyond low-Earth orbit;
- the Orion Multi-Purpose Crew Vehicle (Orion), which is a spacecraft to transport humans beyond low-Earth orbit; and
- Exploration Ground Systems (EGS), which support assembly, test, and launch of the SLS and Orion crew capsule, and recovery of the Orion crew capsule.

NASA is also separately acquiring and testing other systems that will support NASA's long-term lunar exploration goals, including a Human

Landing System that will transport astronauts to and from the lunar surface. We previously reported on these efforts in December 2019 and we are currently conducting work in this area.[1]

The SLS, Orion, and associated ground systems each represent a large, complex technical and programmatic endeavor and all three are in the final phases of integration and testing ahead of the planned Artemis I flight in November 2021. Our prior work has shown this phase of the acquisition process often reveals unforeseen challenges leading to cost growth and schedule delays.[2]

GAO has designated NASA's management of acquisitions as a high-risk area for three decades. In our March 2019 high-risk report, we reported that NASA had taken steps to build capacity to reduce acquisition risk but there was a lack of transparency in NASA's major project cost and schedules, especially for its human spaceflight programs.[3] We also reported that the agency had not taken action on several recommendations related to understanding the long-term costs of its human exploration programs. For example, EGS and SLS do not have a cost and schedule baseline that covers activities beyond the first planned flight (Artemis I), and Orion does not have a baseline beyond the second planned flight (Artemis II). In June 2019, we found that NASA was unlikely to meet its original cost and schedule baselines and that the current SLS baseline did not reflect current mission scope and thereby understated developmental cost growth.[4] We previously found that without transparency into baseline estimates, NASA does not have the data to assess long-term affordability and it will be more difficult for Congress to

[1]GAO, *NASA Lunar Programs: Opportunities Exist to Strengthen Analyses and Plans for Lunar Landing*, GAO-20-68 (Washington, D.C.: Dec. 19, 2019).

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

[3]GAO, *High Risk Series: Substantial Efforts Needed to Achieve Greater Progress on High-Risk Areas*, GAO-19-157SP (Washington, D.C.: Mar. 6, 2019).

[4]GAO, *NASA Human Space Exploration: Persistent Delays and Cost Growth Reinforce Concerns over Management of Programs*, GAO-19-377 (Washington, D.C.: June 19, 2019).

make informed budgetary decisions.[5] Moreover, while human spaceflight programs have inherent technical, design, and integration risks, we have consistently found that management and oversight problems are the real drivers behind program cost and schedule growth.

The House Committee on Appropriations included a provision in its 2017 report for GAO to continue to review NASA's human space exploration programs, specifically the SLS, EGS, and Orion programs.[6] This GAO report is the latest in a series of reports addressing the topic. This report assesses (1) the progress NASA's human space exploration programs are making toward the first test flight—Artemis I—with respect to cost, schedule, and testing, and (2) the extent to which NASA's human space exploration programs are positioned to support the planned Artemis flight schedule beyond Artemis I.

To assess the progress the human space exploration programs are making toward Artemis I, we obtained and analyzed program cost and schedule estimates for the SLS, Orion, and EGS programs through August 2020. We then compared these estimates against baselines to determine cost growth and schedule delays. We did not assess the reliability of NASA's cost and schedule estimates. We also obtained and reviewed quarterly reports and the programs' risk registers, which list the top program risks and their potential cost and schedule impacts, including mitigation efforts to date. We then discussed risks with program officials and Human Exploration and Operations Mission Directorate officials responsible for conducting enterprise schedule risk assessments. To assess program progress in Artemis I testing, we identified key program test events and monitored program progress against test schedules, assessed test event results, and identified risks to remaining test plans by reviewing program documentation. We also interviewed relevant program officials, NASA Independent Verification and Validation Program officials overseeing Artemis software testing, contractor officials, and NASA Stennis Space Center officials involved in testing SLS systems.

To assess the extent to which NASA's human space exploration programs are positioned to support the planned Artemis flight schedule beyond the first test flight, we identified and analyzed contracts NASA

[5]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).

[6]H.R. Rep. No. 115-231, at 62 (2017).

awarded to support the development and production of flight hardware for future missions. We determined contract values based on data NASA reported to the Federal Procurement Data System-Next Generation (FPDS-NG) as of July 2020 and analyzed the contracts to determine the extent to which NASA has identified opportunities for future cost savings. We reviewed relevant portions of the Federal Acquisition Regulation (FAR) and NASA's supplement to the FAR and identified the relative risk assumption by the government associated with the different contract types utilized in support for upcoming missions. We also reviewed relevant program and NASA headquarters documents, including quarterly reports to senior leadership, and met with officials from all three programs as well as Exploration Systems Development (ESD) officials within the Human Exploration and Operations Mission Directorate. Through our analysis of these documents and interviews, we determined the extent to which plans for future missions are stable and the type of programmatic tools NASA is using to oversee the development of new capabilities across these three programs. We supplemented this analysis with a review of NASA's Presidential Budget requests and Appropriations Acts from 2016 to 2020 to identify the purpose stated in the Acts and how much money Congress appropriated to NASA for key efforts.

We also identified the control activities component of internal controls—along with the related principle that management should design control activities to achieve objectives and respond to risks—as significant to both objective one and two. In addition, we identified the risk assessment component of internal controls along with the related principle that management should identify, analyze, and respond to risks related to achieving the defined objectives as significant to both objective one and two. To evaluate NASA's control activities and approaches to assessing risk for these three programs, we obtained and reviewed quarterly reports and the programs' risk registers, which list the top program risks and their potential cost and schedule impacts as well as implemented or planned mitigations. We supplemented our review of these documents with interviews of NASA officials to understand how management controls activities to identify and respond to risks.

We conducted this performance audit from September 2019 to December 2020 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.

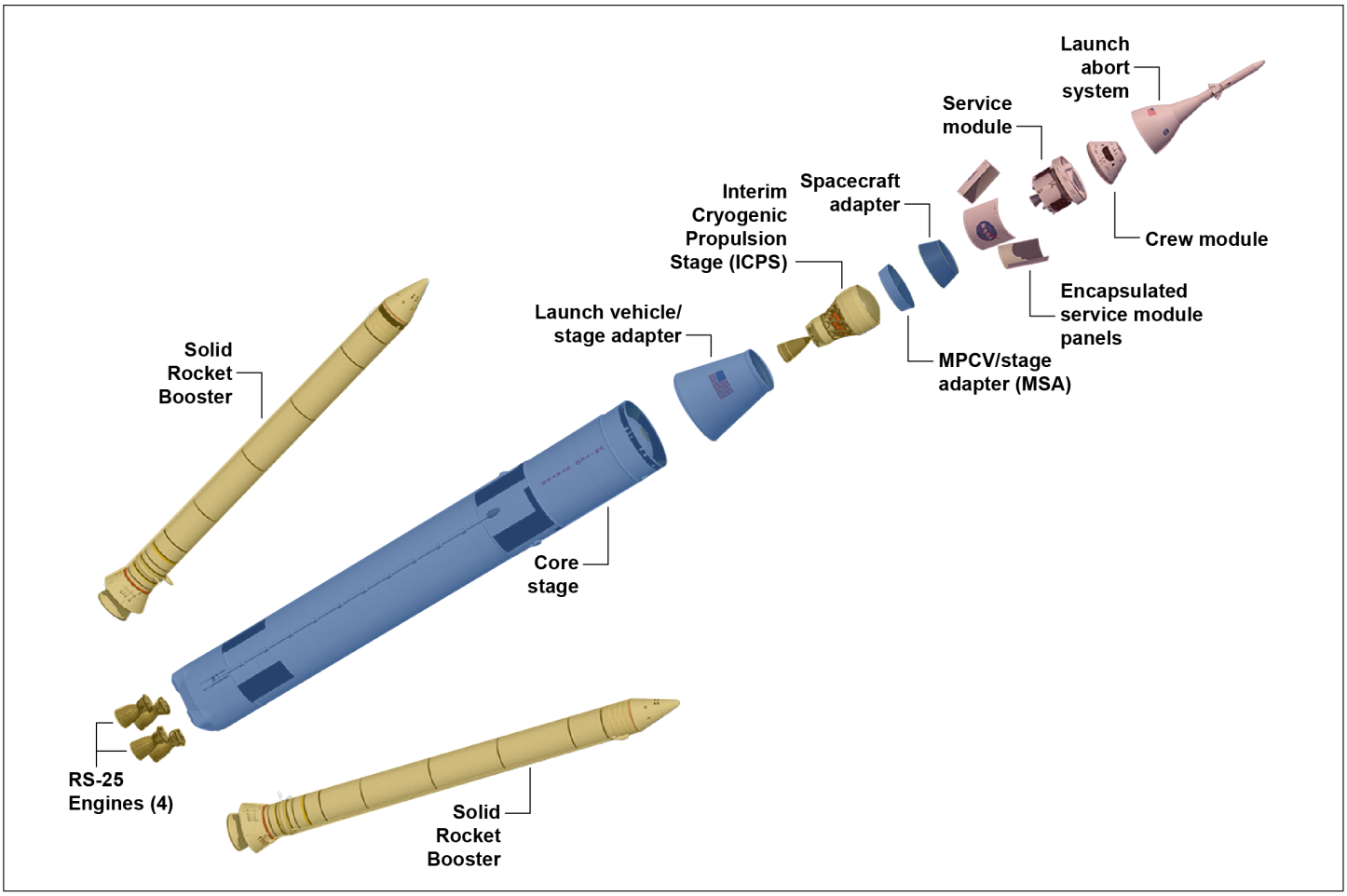
Background

Through the agency's Artemis lunar exploration program, NASA is committed to landing American astronauts, including the first woman and the next man, on the Moon by 2024. NASA plans to collaborate with commercial and international partners to establish sustainable lunar missions by 2028 and to use innovative new technologies and systems to explore more of the Moon than ever before. In the long term, NASA plans to leverage what it learns on and around the Moon to support sending astronauts to Mars. NASA is currently planning eight missions through 2030, with more to follow.

The SLS launch vehicle, the Orion spacecraft, and the ground systems at Kennedy Space Center are key pieces in NASA's lunar exploration plans. During Artemis III, the first planned lunar landing, the SLS vehicle will send astronauts aboard the Orion spacecraft to lunar orbit. Once in lunar orbit, NASA will use a human landing system to transfer astronauts to and from the surface of the moon.

The Exploration Systems Development (ESD) organization within NASA's Human Exploration and Operations Mission Directorate is responsible for managing and integrating the human space exploration programs—SLS, Orion, and EGS—into a human space exploration system. Figure 1 provides details about each SLS hardware element and identifies the major portions of the Orion spacecraft.

Figure 1: Space Launch System and Orion Multi-Purpose Crew Vehicle Hardware



Source: GAO analysis of National Aeronautics and Space Administration data (data and images). | GAO-21-105

NASA established the EGS program to modernize Kennedy Space Center in preparation for integrating hardware, processing and launching SLS and Orion, and recovery of the Orion crew capsule. The EGS program consists of a number of components and processing centers including the Vehicle Assembly Building, Mobile Launchers, Crawler-Transporter, and Launch Pad. Figure 2 is a picture of the Mobile

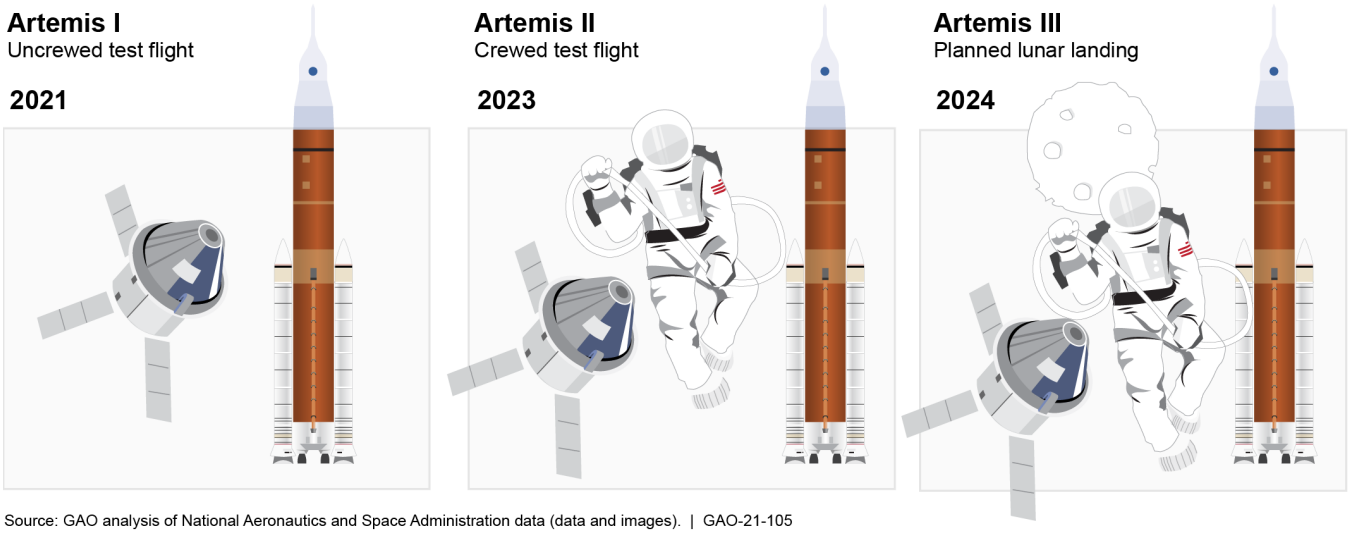
Launcher positioned on top of the Crawler-Transporter outside of the Vehicle Assembly Building.

Figure 2: Mobile Launcher on the Crawler-Transporter outside the Vehicle Assembly Building at Kennedy Space Center

Source: National Aeronautics and Space Administration. | GAO-21-105

During Artemis I, NASA plans to use the SLS vehicle to launch an uncrewed Orion spacecraft to a distant orbit some 70,000 kilometers beyond the Moon. Artemis II will 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 ahead of Artemis III—a crewed lunar landing planned for 2024. Figure 3 shows the proposed schedule for the first three Artemis missions.

Figure 3: Proposed Schedule for First Three Artemis Missions

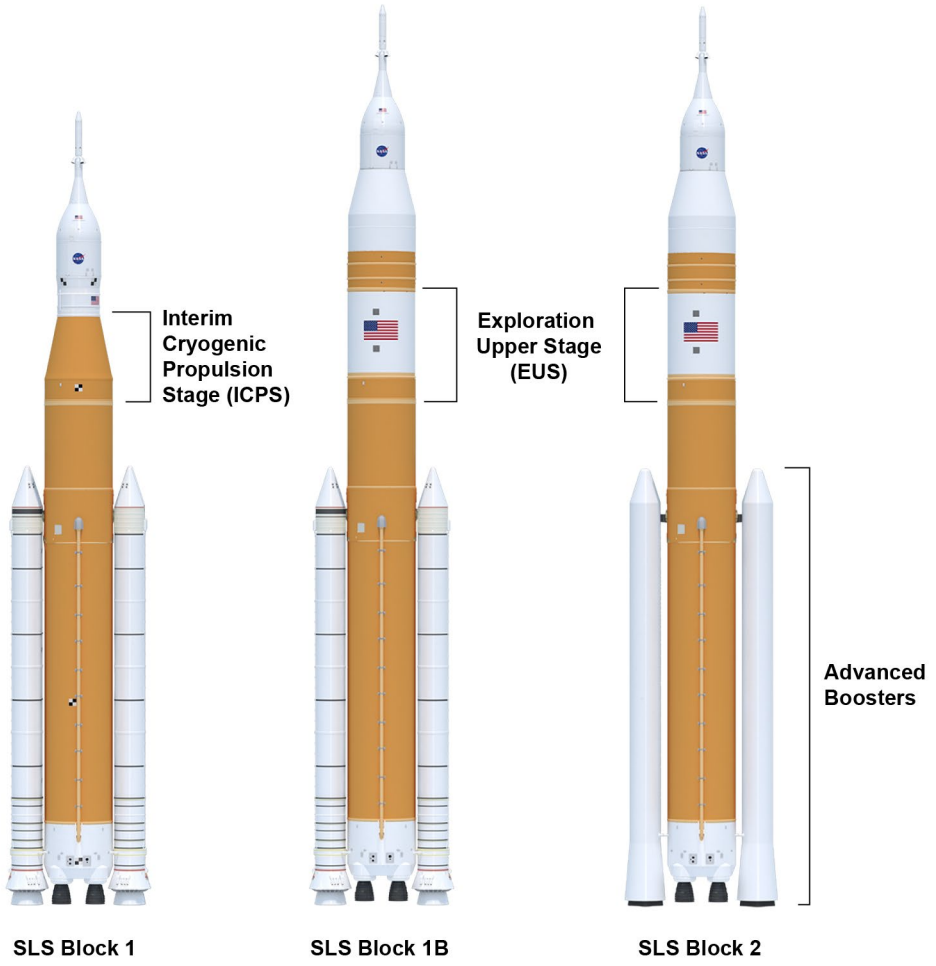


Source: GAO analysis of National Aeronautics and Space Administration data (data and images). | GAO-21-105

NASA plans to use SLS Block 1 for Artemis I through III and increase the capability of SLS for future missions through a series of block upgrades.

- **SLS Block 1** is the current iteration of SLS that NASA plans to use for Artemis I through III. Block 1 will use the core stage, which uses four RS-25 engines from the Space Shuttle program and will be used for all SLS blocks; the interim cryogenic propulsion stage (ICPS), which is an upper stage from the Delta IV rocket used by the Department of Defense; and two five-segment solid rocket boosters derived from existing Space Shuttle program hardware.
- **SLS Block 1B** will retain the core stage and solid rocket boosters from Block 1, but replace the ICPS with a more powerful Exploration Upper Stage (EUS). The Block 1 ICPS uses one RL-10 engine with 25,000 pounds of thrust, whereas the EUS on Block 1B will have four RL-10 engines with a total of 97,000 pounds of thrust. Utilizing the EUS increases the amount of cargo the SLS can deliver to the Moon.
- **SLS Block 2** will retain the core stage and EUS but replace the legacy Shuttle-era solid rocket boosters with improved advanced boosters, allowing even heavier payloads to be lifted into space. Figure 4 shows NASA's planned SLS upgrades.

Figure 4: Space Launch System Planned Block Upgrades



Source: GAO analysis of National Aeronautics and Space Administration data (data and images). | GAO-21-105

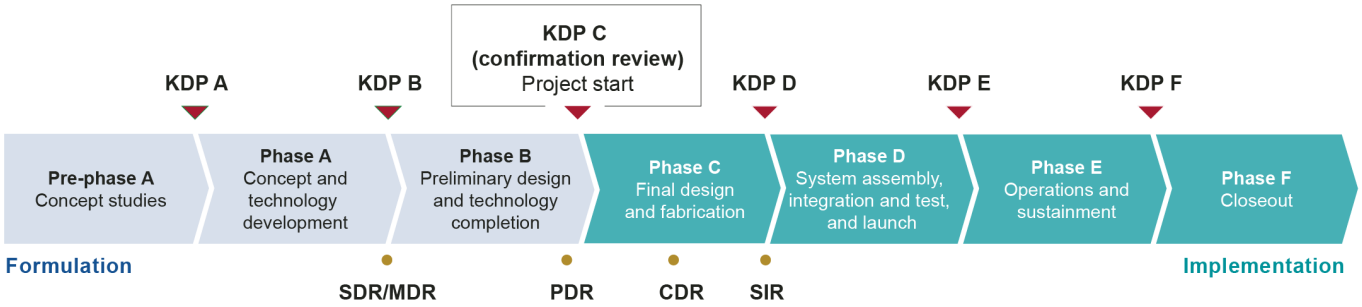
NASA Acquisition Life Cycle

Leading practices for acquisition programs call for establishing baselines that match cost and schedule resources to requirements and rationally balance cost, schedule, and performance.[7] Our work has also shown that validating this match before committing resources to development helps

[7]GAO, *Best Practices: Using a Knowledge-based Approach to Improve Weapon Acquisition,* GAO-04-386SP (Washington, D.C.: Jan. 1, 2004); and *Best Practices: Better Matching of Needs and Resources Will lead to Better Weapon System Outcomes*, GAO-01-288 (Washington, D.C.: Mar. 8, 2001).

to mitigate the risks inherent in complex acquisition programs such as SLS, Orion, and EGS.[8] We have reported that within NASA's acquisition life cycle, resources should be matched to requirements at key decision point (KDP) C, the review that commits the program to formal cost and schedule baselines and marks the transition from the formulation phase into the implementation phase.[9] Figure 5 depicts NASA's life cycle for space flight projects.

Figure 5: NASA's Acquisition Life Cycle for Space Flight Programs



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: GAO presentation of National Aeronautics and Space Administration information. | GAO-21-105

[8]GAO, *Defense Acquisitions: Key Decisions to Be Made on Future Combat System*, GAO-07-376 (Washington, D.C.: Mar. 15, 2007); *Defense Acquisitions: Improved Business Case Key for Future Combat System's Success*, GAO-06-564T (Washington, D.C.: Apr. 4, 2006); *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); and *NASA's Space Vision: Business Case for Prometheus 1 Needed to Ensure Requirements Match Available Resources*, GAO-05-242 (Washington, D.C.: Feb. 28, 2005).

[9]GAO, *NASA: Agency Has Taken Steps Toward Making Sound Investment Decisions for Ares I but Still Faces Challenging Knowledge Gaps*, GAO-08-51 (Washington, D.C.: Oct. 31, 2007); and GAO-06-218.

For the programs discussed in this report, NASA is to establish an agency baseline commitment—the cost and schedule baselines against which the program may be measured—at KDP C.[10] See table 1 for an overview of NASA program replans and rebaselines, which occur for various reasons, including when certain conditions in the agency baseline commitment are no longer met.

Table 1: Characteristics of Program Replans and Rebaselines

	Description	Potential Congressional Reporting
Replan	A replan is a process by which a program updates or modifies its plans. It generally is driven by changes in program or project cost parameters, such as if development cost growth is 15 percent or more of the estimate in the baseline report or a major milestone is delayed by 6 months or more from the baseline's date. A replan does not require a new project baseline to be established.	When the NASA Administrator determines that development cost growth is likely to exceed the development cost estimate by 15 percent or more, or a program milestone is likely to be delayed from the baseline's date by 6 months or more, NASA must submit a report to the Committee on Science, Space, and Technology of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate.[a]
Rebaseline	A rebaseline is a process initiated if the estimated development cost exceeds the baseline development cost estimate by 30 percent or more or if the NASA Associate Administrator determines other events make a rebaseline appropriate.	When the NASA Administrator determines that development cost growth is likely to exceed the development cost estimate by 15 percent or more, or a program milestone is likely to be delayed from the baseline's date by 6 months or more, NASA must submit a report to the Committee on Science, Space, and Technology of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate.[a] Should a program exceed its development cost baseline by more than 30 percent, the program must be reauthorized by the Congress and rebaselined in order for the contractor to continue work beyond a specified time frame.[b]

Source: GAO analysis of NASA policy and 51 U.S.C. § 30104. | GAO-21-105

[a]51 U.S.C. § 30104(e)(1).

[b]51 U.S.C. § 30104(f).

Coronavirus Disease 2019

In March 2020, during the course of this engagement, the President declared a nationwide state of emergency as a result of the spread of the Coronavirus Disease 2019 (COVID-19). States and many employers—including locations where work on human space exploration programs activities were ongoing—implemented changes to curb the spread of the virus. In some instances these changes included closing installations,

[10]NASA space flight policy addresses several program and project types. The efforts discussed in this report are a type referred to as "single-project programs." Unless otherwise noted, the NASA policy discussed in this report is the policy applicable to single-project programs.

affecting human space exploration work for varying lengths of time. NASA is still assessing the effect of COVID-19 on these programs.

Significant Artemis I Delays and Cost Growth Place Pressure on the Schedule for Future Missions, and Complex Testing and Integration Remain

In June 2020, the NASA Administrator postponed the Artemis I mission an additional 17 months to November 2021 due to program delays and remaining schedule risk to integration and testing of the three systems in preparation for this uncrewed flight test. As a result of this most recent delay, NASA has postponed the Artemis I mission a total of 36 months past the original November 2018 launch date. Accompanying this delay, NASA estimates the SLS and EGS programs will exceed original development cost estimates by over $3 billion. NASA completed the analysis to inform this new launch date and associated cost estimates during the initial stages of the COVID-19 emergency, and as a result, it does not reflect any cost or schedule effects experienced to date from COVID-19. Due in part to COVID-19, manufacturing delays, and remaining risks, there is already risk that this new launch date will not be met. NASA has successfully completed some key test events to evaluate readiness to support the first uncrewed test flight, but complex SLS core stage testing, integration of the SLS and Orion spacecraft, and final integrated testing remain to be completed prior to the Artemis I launch.

Revised Artemis I Estimates Reflect an Additional 17 Months of Delays and Over $2 Billion of Additional Development Cost Growth

Schedule and Cost Growth

In June 2020, the NASA Administrator approved postponing the Artemis I mission an additional 17 months, from June 2020 to November 2021. At the same time, the NASA Administrator announced a development cost estimate increase of $1.9 billion for the SLS program and $173 million for the EGS program. As seen in table 2, this is the second time NASA changed the committed Artemis I launch date since it established the original November 2018 launch date. Since NASA established a baseline commitment for these programs, it delayed the mission a total of 36

months and development cost estimates for the SLS and EGS programs increased by over a combined $3 billion.[11]

Table 2: Space Launch System and Exploration Ground Systems Program Development Cost and Schedule Baselines and Revised Estimates for Artemis I (cost in billions)

	Agency Baseline Commitment (2014)		Replan (December 2017)		Rebaseline (June 2020)			
Program	Development Cost (dollars)	Launch Date	Development Cost (dollars)	Launch Date	Development Cost (dollars)	Launch Date	Development percentage cost growth	Delay from November 2018
Space Launch System	6.390[a]	November 2018	7.169	June 2020	9.108	November 2021	42.5 percent	36 months
Exploration Ground Systems	1.843	November 2018	2.265	June 2020	2.438	November 2021	32.3 percent	36 months

Source: GAO presentation of National Aeronautics and Space Administration data. | GAO-21-105.

[a]In August 2020, NASA reduced the SLS development baseline from $7.021 billion to $6.390 billion to reflect the removal of some SLS engines sustainment costs that NASA is no longer associating with the Artemis I development baseline.

The revised launch date reflects remaining schedule risk to Artemis I integration activities, but does not include any delays resulting from COVID-19. NASA stated that this new baseline is the culmination of an analysis that precedes the agency's response to the COVID-19 pandemic. Specifically, in November 2018, senior NASA officials acknowledged that NASA was unlikely to meet the June 2020 launch date due to continued SLS and Orion production challenges and potential delays resulting from SLS and Orion testing and final integration and testing.[12] NASA initiated the analysis for the rebaselining effort in February 2020 and briefed NASA's executive council on the results in April 2020. NASA officials stated the new launch date and cost estimates do not take into account any cost and schedule impacts that may result from the steps the agency has taken to protect its government and contractor workforce from COVID-19.

NASA's planned November 2021 Artemis I launch date included 5 months of schedule reserve for the EGS program. Schedule reserves are extra time in project schedules that can be allocated to specific activities,

[11]The Orion program baseline cost and schedule is measured through the Artemis II mission. NASA does not plan to complete revised estimates for the Orion program before spring 2021.

[12]GAO-19-377.

elements, and major subsystems to mitigate delays or address unforeseen risks. As of July 2020, due in part to COVID-19 and manufacturing delays, the SLS program had slipped the schedule to deliver the core stage to EGS by 2 months, from November 2020 to January 2021. EGS program officials stated the program can still support a November 2021 launch but that it will likely use all planned schedule margin to do so because of the risks associated with first time integration of SLS, Orion, and ground systems. Further, EGS program officials stated that any additional delays that result in SLS delivering the core stage to the EGS program beyond January 2021 could potentially delay the November 2021 launch date.

Subsequently, in November 2020, NASA reported additional delays for the SLS program but anticipated maintaining a January 2021 delivery date of the core stage to Kennedy Space Center. Likewise, at the end of November 2020, the Orion program reported that while completing final assembly, engineers identified an issue with Orion's crew module adapter. At the time of this report, NASA was still troubleshooting this issue and determining if it would affect the program's planned schedule.

NASA attributes increased development costs for the SLS and EGS programs to the longer timeframes caused by the delayed launch readiness date. In addition, in January 2020, NASA completed a contract renegotiation with the SLS core stage contractor, Boeing, after both determined Boeing was going to exceed the cost-reimbursement contract's not-to-exceed estimated total cost. The increased costs are also reflected in this new SLS cost estimate.

Artemis I Schedule Delays Will Place Pressure on Future Missions Schedule

Any delay to Artemis I will affect the timing of the Artemis II mission due to Orion spacecraft work that is planned to occur between these two missions. For example, the Orion program plans to reuse some avionics from the Artemis I crew module, including GPS receivers and antennas, on the Artemis II crew module. According to program officials, NASA will require a minimum of 20 months to refurbish and install these reused components, complete the crew and service module, and complete the EGS prelaunch processing activities. NASA plans to launch Artemis II in April 2023. However, as a result of the delay to the Artemis I mission to November 2021 and the minimum 20 months required between the two missions, the earliest NASA could launch Artemis II is July 2023.

Further, the delay of the first two Artemis missions places more pressure on the agency's plans for the Artemis III lunar landing in 2024. Since NASA now plans to conduct the Artemis III mission in September 2024,

NASA will have 14 months between Artemis II and Artemis III—2 to 3 months fewer than prior plans. As a result, NASA has less time to address any issues identified during the Artemis II test flight before the lunar landing flight. Additionally, a delay to the Artemis III mission may affect NASA's plans to begin annual Artemis missions starting with Artemis IV in 2026.

NASA Has Completed Some Key Tests for Artemis I Systems, but Complex Testing and Integration Activities Remain

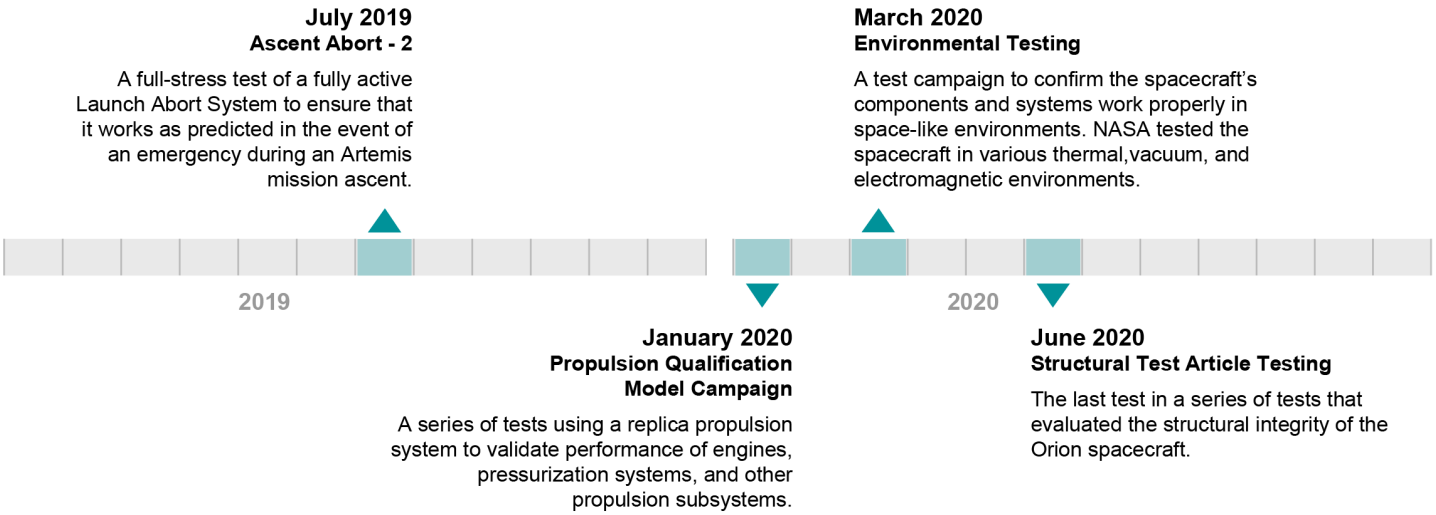
Since our June 2019 report, each program successfully completed some key test events in advance of the Artemis I uncrewed test flight.[13] However, additional events remain before launch, such as complex testing of the SLS core stage, integration of the SLS and Orion spacecraft, and final integrated testing.

Key Testing Completed toward Artemis I

Orion: The Orion program has nearly completed planned testing needed to support the Artemis I mission, with the exception of final assembly activities ahead of the final integrated testing that will occur before launch. As seen in figure 6, the Orion program completed key systems and integrated Orion spacecraft testing. Orion program officials indicated the program successfully completed the last test of the Artemis I structural test article in June 2020. That test concluded all Orion vehicle-specific testing prior to integration with SLS and integrated testing.

[13]GAO-19-377.

Figure 6: Recent Orion Program Test Events for Artemis I



Source: GAO presentation of National Aeronautics and Space Administration information. | GAO-21-105

Notable among the tests that the program completed, in March 2020, testing confirmed that the integrated Orion spacecraft components and systems function properly in space-like conditions. Figure 7 below depicts the Orion spacecraft at Plum Brook Station in Sandusky, Ohio for these tests.

Figure 7: Orion Spacecraft in the Thermal Vacuum Chamber at Plum Brook Station, Sandusky, Ohio

Source: National Aeronautics and Space Administration. | GAO-21-105

SLS: The SLS program successfully completed several tests on systems in the last year. These tests included completing core stage structural tests and the integrated core stage Final Integrated Functional Test, following the completion of the majority of core stage production.[14] According to a program official, the Final Integrated Functional Test confirmed that all core stage flight avionics systems are properly functioning and communicating. Following this test, the program shipped the SLS core stage to Stennis Space Center where the program began preparing for integrated core stage testing—referred to as Green Run testing. In January 2020, the SLS program began the Green Run test campaign. As of November 2020, NASA reported completing six of eight Green Run test events. This included applying forces simulating launch to the core stage structure, and exercising safety systems that shut down operations if there is a problem.

[14]The SLS program deferred some production work—that was not completed prior to the core stage being shipped from the Michoud Assembly Facility—to be conducted at Stennis Space Center.

EGS: The EGS program has made progress in preparing to conduct integrated testing with the SLS and Orion spacecraft for the Artemis I mission. The EGS program completed multi-element verification and validation of the Mobile Launcher and the launch pad in January 2020. Multi-element verification and validation determines whether the launch and processing systems at Kennedy Space Center meet program requirements and specifications and can operate together to fulfill their intended purpose.

Remaining Tests and Integration for Artemis I

While some testing progress has been made, NASA has yet to complete Green Run testing of the SLS core stage mated with the engines and the subsequent integrated testing of the SLS and Orion vehicles at Kennedy Space Center. These challenging tests remain ahead for these programs and, according to program risk documents, will likely identify technical issues requiring both time and money to address.

SLS: The primary critical path for Artemis I is the completion of SLS core stage testing and delivery to Kennedy Space Center for integration with other Artemis systems. As part of the Green Run test series, the SLS program still has to validate the performance of the integrated core stage with a hot fire test. During this test, the SLS program will fire the core stage's four engines for 500 seconds. At the time of our review, NASA was planning for this test to occur in late October or early November 2020. Subsequently, NASA stated that the test event is now delayed until December 2020 as a result of weather related delays and the need to repair a valve that supplies liquid hydrogen to the RS-25 engines. Figure 8 shows the SLS core stage at Stennis Space Center.

Figure 8: Space Launch System Core Stage in Stennis Space Center Test Stand

Source: National Aeronautics and Space Administration. | GAO-21-105

Prior to proceeding to the hot fire test, NASA must complete the wet dress rehearsal during which core stage liquid oxygen and hydrogen tanks are filled, pressurized, tested, and then drained. We previously reported that one of the program's top remaining technical risks to the Green Run is that the core stage may develop leaks when it is filled with fuel.[15] According to officials, while the program has conducted extensive scaled testing of core stage gaskets and seals, it is difficult to precisely predict how large volumes of liquid hydrogen and oxygen will affect the stage. The program continues to identify potential leaks as one of its top program risks. Should leaks or other issues be discovered, the program will need time to assess and mitigate difficulties or glitches, which could delay the completion of Green Run testing, shipping the core stage to Kennedy Space Center, and integrated testing.

EGS: Following the delivery of the SLS core stage, Orion spacecraft, and other systems to Kennedy Space Center, the EGS program is responsible for Artemis I integrated operations, which include stacking and integrated

[15]GAO, *NASA: Assessments of Major Projects*, GAO-20-405 (Washington, D.C.: Apr. 29, 2020).

testing. The EGS program is tracking several risks for these operations, most notably software development and schedule risks related to Artemis integration.

- The EGS program has made progress toward design certification reviews of the Spaceport Command and Control System—a major software system that will operate and monitor ground equipment such as pumps, motors, and valves, and monitor Orion and SLS during processing and integrated testing. However, EGS officials said that the program has encountered issues with the software that may delay the design certification review that certifies the software meets Artemis I requirements.
- Similarly, Ground and Flight Application Software—the interface with flight systems and ground crews—is fully developed, but some validation and verification activities remain. EGS officials indicated that COVID-19 limited access to the SLS software integration laboratory, delaying the completion of validation and verification.
- Additionally, the EGS program identified the learning curve related to first time assembly and processing of the Artemis I vehicles during integrated operations as the top program risk. The program plans to mitigate this risk in part by executing tasks to provide EGS personnel opportunities to become familiar with the operation of support systems and simulated flight hardware interfaces. The EGS program's risk tracking system indicates that there are up to 5 months of risk to the program schedule during these final activities before the Artemis I launch.

Uncertain Plans, Unproven Cost Assumptions, and Limited Oversight Place Future Artemis Missions at Increased Risk of Poor Outcomes

NASA has not clearly defined plans for developing capabilities such as SLS Block 1B and Block 2 to support future Artemis missions. This has created uncertainty within the programs where development efforts are ongoing. To support these missions, NASA is awarding additional development and production contracts to the contractors developing the initial systems. The contracts are predominantly cost-reimbursement type, under which the government bears the risk of increases in the costs. NASA is taking steps to control long-term program costs by planning to transition to fixed-price type contracting and other cost reduction strategies, but it will be years before NASA is in a position to do so. Finally, NASA currently lacks effective programmatic tools to maintain oversight and measure programs' cost and schedule performance for ongoing development efforts worth billions of dollars in support of future missions.

NASA Lacks Clear Requirements or Time Frames for Ongoing Development Efforts to Support Future Artemis Missions

NASA plans to increase the capability of the SLS launch vehicle through the development of a more powerful upper stage—EUS—and advanced boosters to support future Artemis missions. However, NASA continues to change the time frame for when these capabilities will actually be needed. For example, over a 10-month period during the course of this review, NASA developed four different flight schedules. Each flight schedule contained different dates for Artemis missions and varying plans for the use of future SLS Block 1B and Block 2 capabilities. Our analysis identified two contributing factors to these changes:

- The Artemis I date continues to slip, which affects future missions. As discussed previously, Artemis II can launch no sooner than 20 months after Artemis I. Continued uncertainty surrounding the Artemis I schedule has led to frequent shifting of other mission dates.
- The SLS program also faces a challenge balancing direction from NASA headquarters—focused on supporting production of SLS Block 1 to support near-term missions—with congressional direction to develop the EUS capability, which NASA plans to use for anticipated future missions. Specifically, NASA has received funding for EUS, a key upgrade for SLS Block 1B and Block 2, but NASA has not made it clear how and when it plans to use future SLS Block 1B and Block 2 capabilities. For example, since the fiscal year 2017 budget, Congress has appropriated a total of $1.05 billion specifically for EUS development. However, NASA did not request funding for EUS in either its fiscal year 2020 or fiscal year 2021 budget requests, stating that it was prioritizing resources to finish development of the SLS Block 1 capability that will be used for the Artemis I and II test flights and planned 2024 lunar mission. In fiscal year 2020, Congress also appropriated $300 million for EUS development.[16]

These challenges have also been exacerbated in some instances by NASA changing leadership responsible for the programs working on major development efforts including:

SLS Block 1B: The development effort for the more powerful SLS Block 1B has been a stop-start effort thus far. The SLS program held the EUS preliminary design review in November 2016, at which point EUS requirements were for a non-Trans Lunar Injection (TLI) trajectory. TLI is a propulsive maneuver used to set a spacecraft on a trajectory that will cause it to arrive at lunar orbit. In August 2018, just as EUS was

[16]NASA officials told us that the specific appropriations for EUS are available for EUS and other interfaces and software that support EUS. See, e.g., Consolidated Appropriations Act, 2020, Pub L. No. 116-93, div. B, tit. III (2019).

approaching critical design review, NASA halted work to update requirements including changing the EUS requirement to include a TLI trajectory. Work resumed in early 2020, but then in April 2020, the SLS program received direction from leadership at NASA headquarters to update EUS requirements specifically for a TLI-optimized cargo mission. Shifting between TLI and non-TLI, as well as between crew versus cargo, affects the design of the SLS Block 1B. As of June 2020, following a leadership change, program officials expected NASA headquarters to change requirements once again to support a TLI-optimized crewed rather than cargo mission, but were still waiting for official direction from NASA headquarters. The program indicated that it expects to implement this design configuration for the EUS critical design review planned for December 2020.

Similarly, the EGS program has faced starts and stops with SLS Block 1B work related to modifications required at Kennedy Space Center to support the new EUS. This includes the program recently issuing two task orders under two existing engineering services contracts totaling approximately $1.4 million. According to program officials, under the task orders, the contractors were to perform design work to support a schedule that was ultimately discarded. According to program officials, in January 2020, NASA headquarters directed the EGS program to investigate the ability to conduct nearly simultaneous launches of a crewed SLS Block 1 and a cargo SLS Block 1B mission in 2024. To support this change in direction, the EGS program issued two task orders to conduct design studies to investigate reactivating a portion of the Vehicle Assembly Building, which has not been used since the Shuttle program ended in 2011. The EGS program was then notified by NASA headquarters that it should focus on a crewed Block 1B mission in 2026 instead of a cargo Block 1B mission in September 2024. However, EGS officials told us the program is continuing these Vehicle Assembly Building design studies through to a preliminary design review even though the work is no longer currently planned. Program officials stated that completing the preliminary design would provide a natural stopping point in the work and then the designs would be available should direction change again.

The EGS program must still modify the part of the Vehicle Assembly Building currently planned for Block 1 to support Block 1B. This includes adding additional platforms and work stations. However, work within this building cannot take place while NASA is supporting ongoing Artemis missions. The EGS program must fit these modifications into windows between Artemis I, II, and III. EGS officials told us they had hoped to start

work on these modifications prior to the Artemis I launch, but have yet to receive funding to begin this work. NASA officials expressed concern that delaying the start of this work until after Artemis I could ultimately affect the ability of the ground systems to support a Block 1B launch on schedule.

Both SLS and EGS program officials noted how difficult it has been to respond to changing direction from NASA headquarters on when the programs must support a Block 1B launch. For example, SLS officials explained that they had to accelerate Block 1B work—including the EUS critical design review and work on the first EUS—to support the proposed 2024 Block 1B cargo launch. But with the recent direction to not pursue this mission, the program does not need to ramp up Block 1B work so quickly. Despite the anticipated schedule change, the program plans to keep the EUS critical design review in December 2020. However, SLS officials told us the program will not continue to accelerate the rest of the production effort for the first EUS and does not plan to accelerate other activities after the EUS critical design review.

EGS officials noted that while they are often asked to look into alternate schedules, direction to look into a potential 2024 Block 1B cargo launch was an especially large effort. Officials explained that they do not typically award contracts to support alternate schedule analyses, and the EGS program now has these task orders in place even though this work does not support any mission-critical EGS activities.

Orion Docking System: NASA determined that it needs to develop a docking system to support Artemis III, the crewed lunar landing planned for 2024. This docking system, however, was not part of the original Orion baseline. The Orion program plans to use a modified version of the existing NASA docking system used for the International Space Station. Work on the docking system is ongoing with a critical design review scheduled for March 2021. According to program officials, in order to reduce risk for Artemis III, NASA intends to demonstrate proximity operations without actually docking on the Artemis II crewed test flight.

In June 2020, NASA released a new Artemis flight schedule. This schedule calls for the first SLS Block 1B mission to be a crewed mission in March 2026 and the first SLS Block 2 mission to be in fiscal year 2031. If NASA remains committed to this schedule, it should help provide stability and alleviate some of the churn these programs previously experienced. However, it will be important for NASA to continue to define realistic schedule goals for these major development efforts and

communicate any schedule changes to the programs clearly and in a timely manner to avoid potentially unnecessary disruption to ongoing work. We will continue to assess NASA's Artemis schedule moving forward and monitor these major development efforts.

In addition to the SLS Block 1B and Orion Docking System, NASA also faces significant development work for the SLS Block 2 variant. This variant will include the EUS and new solid rocket boosters to eventually replace legacy boosters from the Shuttle program. NASA has enough legacy Shuttle boosters for only the first eight Artemis missions. According to program officials, the Block 2 booster will include a new composite casing, propellant, and thrust vector control system. NASA only has a notional date for Artemis IX, but this new booster development will take years, with a critical design review scheduled to begin in 2025.

Significant Artemis Resources Are Subject to Cost Growth and Achievability of NASA Long-Term Cost Reduction Plans Will Remain Uncertain for Years

Even with the schedule uncertainty surrounding future missions, NASA is awarding contracts for major systems across the Orion, EGS, and SLS programs to support, in some cases, up to 14 Artemis missions that are valued at approximately $30 billion. This value will increase once final agreement is reached on contract terms and conditions for the SLS Production and Evolution Contract and Booster Production and Operations Contract. See table 3.

Table 3: Major Contracts across the Orion, Exploration Ground Systems, and Space Launch System Programs

Contract and Contract Type[a]	Contractor	Description	Contracting Actions since June 2019	Current Contract Value (dollars in billions)	Obligations (dollars in billions)
Orion					
Orion Development Actions					
Orion design, development, test, and evaluation cost-plus-award-fee (CPAF)	Lockheed Martin Corporation	Design, build, and test two Orion Spacecraft to support Artemis I and II	Recent modifications extended the contract's period of performance to 2023 and increased contract value by $1.8 billion	14.32	12.97
Orion Production Actions					
Orion production and operations, indefinite-delivery indefinite-quantity (IDIQ) with cost-plus-incentive-fee (CPIF) and firm-fixed-price (FFP) orders	Lockheed Martin Corporation	Production of a planned minimum of six and maximum 12 Orion Spacecraft missions to support Artemis III through XIV	Program issued orders supporting Artemis III through V in September 2019 and plans to reuse hardware for Artemis VI through VIII	2.70	0.194
Exploration Ground Systems (EGS)					
EGS Development Actions					
Mobile Launcher 2 CPAF	Bechtel National, Inc.	Design and build Mobile Launcher 2 to support Block 1B configuration for Artemis IV and beyond	NASA awarded the contract in June 2019	0.402	0.311
Space Launch System (SLS)					
SLS Development Actions					
SLS stages design, development, test, and evaluation CPAF	The Boeing Company	Design, build, and test core stage 1 and core stage 2 to support Artemis I and II; design, build, and test an Exploration Upper Stage to support Artemis IV.	A recent modification incorporated long lead items for Artemis III, additional development for the first exploration upper stage for Artemis IV, and increased contract value by $2.03 billion	9.10[b]	6.77
SLS Development & Production Actions					
Boosters CPAF	Northrop Grumman[d]	Reuse of six boosters updated from heritage hardware to support Artemis I through III	A recent modification increased the contract value by $107 million	4.22	3.80

Contract and Contract Type[a]	Contractor	Description	Contracting Actions since June 2019	Current Contract Value (dollars in billions)	Obligations (dollars in billions)
RS-25 Adaptation CPAF	Aerojet Rocketdyne	Adaptation of 16 heritage RS-25 engines to support Artemis I through IV	None. The contract's period of performance was concluded in September 2020.	2.06[c]	2.06
Interim cryogenic propulsion stage CPAF	The Boeing Company	Provide three ICPS to support Artemis I through III	NASA expects to definitize undefinitized contract actions for second and third interim cryogenic propulsion system by November 2020	0.591	0.513
RS-25 Restart CPAF	Aerojet Rocketdyne	Restart production and certification of 24 new RS-25 engines to support Artemis V through IX	A recent modification included 18 additional engines for an additional $1.8 billion	3.49	1.13
SLS Production and Evolution Contract (contact type to be determined)	The Boeing Company	Production of two core stages, material for an additional eight core stages to support Artemis III - XII; and material for eight Exploration Upper Stages to support Artemis V - XII	Awarded letter contract—a type of contract with undefinitized terms—in October 2019 for Boeing to start work on core stage production for Artemis III.[e] Definitization for entire scope of work expected in March 2021	To be determined	To be determined
Booster Production and Operations Contract (contract type to be determined)	Northrop Grumman[d]	Provide the existing solid rocket boosters for Artemis IV through VIII and develop new boosters for use in Artemis IX	Letter contract awarded in June 2020 for Northrop Grumman to start work on additional boosters for Artemis IV through VIII and begin development of advanced boosters	To be determined	To be determined

Source: GAO analysis of Federal Procurement Data System-Next Generation (FPDS-NG) data and National Aeronautics and Space Administration (NASA) documents. | GAO-21-105

[a]The contract type information in this table represents the contract type NASA reported in the Federal Procurement Data System-Next Generation (FPDS-NG). FPDS-NG instructs that if an award has more than one contract type, the agency is to report the type with greater contract value, or, for agencies that report multiple actions, follow agency instructions.

[b]According to officials, approximately $708.89 million of the SLS Stages Design, Development, Test, and Evaluation total contract value supported the development of the Ares I First Stage for the canceled Constellation Program.

[c]According to officials, approximately $1.49 billion of the RS-25 Adaptation total contract value supported the development of the J-2X engines for the canceled Constellation program and risk mitigation under the American Recovery and Reinvestment Act.

[d]This contract was awarded to ATK Launch Systems Inc. Since the award, ATK Launch Systems was acquired by Northrop Grumman.

[e]The Federal Acquisition Regulation (FAR) describes a letter contract as a written preliminary contractual instrument that authorizes the contractor to begin immediately manufacturing supplies or performing services. FAR § 16.603-1.

NASA is awarding or modifying existing contracts to support missions several years into the future because of the length of time it takes to develop and build components. However, NASA has not yet achieved a stable production environment and continues to face significant development work to execute its planned Artemis missions. As noted in the table, the contracts to support these efforts are predominantly cost-reimbursement type.[17] The Federal Acquisition Regulation (FAR) provides a number of factors that a contracting officer should consider in selecting and negotiating the contract type, including the type and complexity of the requirement. For this factor, the FAR states that complex requirements, particularly those unique to the government, usually result in greater risk assumption by the government, but that as a requirement recurs or as quantity production begins, the cost risk should shift to the contractor, and a fixed-price contract should be considered. However, without the knowledge needed to use fixed-price type contracts, the government will continue to bear increased cost risk when using cost-type contracts.

As reflected in table 3, NASA is also utilizing undefinitized contract actions and letter contracts, but is taking steps to mitigate some of the risk.[18] In general, undefinitized contract actions authorize contractors to begin work before reaching a final agreement with the government on

[17]Under the Federal Acquisition Regulation, a variety of contract types are available to the government. Among other things, the contract type determines how risk is allocated between the government and the contractor. For example, under firm-fixed-price contracts, the contractor has full responsibility for performance costs. Under cost-reimbursement contracts, the government provides for the payment of allowable incurred costs, to the extent prescribed in the contract.

[18]The FAR describes a letter contract as a written preliminary contractual instrument that authorizes the contractor to begin immediately manufacturing supplies or performing services. FAR § 16.603-1. The FAR states that a letter contract may be used when the government's interests demand that the contractor be given a binding commitment so that work can start immediately and negotiating a definitive contract is not possible in sufficient time to meet the requirement. FAR § 16.603-2(a). NASA's supplement to the FAR defines an undefinitized contract action as a unilateral or bilateral contract modification, or a delivery/task order in which the final price or estimated cost and fee have not been negotiated and mutually agreed to by NASA and the contractor. NFS § 1843.7001.

contract terms and conditions. Our previous work has demonstrated the risks associated with Department of Defense undefinitized contract actions, which include letter contracts.[19] These actions can allow the government to fulfill requirements that are urgent or need to be met quickly when there is insufficient time to use normal contracting vehicles. However, our prior work has noted that these types of actions can pose risks to the government, such as when contractors lack incentives to control costs before all contract terms and conditions are defined.[20]

For example, NASA awarded Boeing a letter contract—a type of contract with undefinitized terms—for production of two SLS core stages, materials for eight additional SLS core stages, and materials for eight EUS to support future Artemis missions. The program, however, does not plan to definitize this contract until March 2021—17 months after its initial award.[21] NASA officials explained that they awarded the contract so Boeing could order long-lead items for future production in order to keep to schedule. However, NASA did not issue a request for proposal to Boeing to definitize the contract until April 2020 due in part to changing government requirements and the complexity of the proposed effort. Officials told us that while this contract is undefinitized, they are managing the contractor to interim milestones and scope.

While the use of cost type contracts and undefinitized contract actions do pose the possibility of increased costs risks, NASA has taken steps to control long-term costs by planning to transition from cost-type contracting to fixed-price contracting for production efforts as the programs gain knowledge. The SLS program plans to control long-term production costs of SLS core stages and EUS by structuring the SLS Stages Production and Evolution contract to allow a transition from cost-type to firm-fixed-price deliverables. Program officials told us they expect the first series of core stages and EUS under this contract to be produced under cost-type orders, but they expect to eventually transition to the use of firm-fixed-price orders as Boeing develops more expertise and certainty in the production of core stages and EUS. Negotiations for when

[19]GAO-14-631, GAO, *Defense Contracting: Observations on Air Force Use of Undefinitized Contract Actions,* GAO-15-496R (Washington, D.C.: May 18, 2015).

[20]GAO-14-631.

[21]The FAR requires that a letter contract contain a schedule that provides for definitization of the contract within 180 days after the date of the contract or before completion of 40 percent of the work to be performed, whichever occurs first. FAR § 16.603-2(c).The FAR also provides that the contracting officer may, in extreme cases and according to agency procedures, authorize an additional period. FAR § 16.603-2(c).

this transition will occur are ongoing and will be finalized when the contract is definitized. As a result, the point at which the cost risk will shift from the government to the contractor through the use of firm-fixed-price type contracting remains unknown.

The Orion program has also taken steps to reduce or control costs of future Orion spacecraft produced under the Orion Production and Operations Contract (OPOC), but the extent to which these steps will achieve desired cost savings remains uncertain. NASA is using a contract structure that shifts the cost risk to Lockheed Martin as the program moves forward. Similar to the plans for the SLS Stages Production and Evolution contract, orders for the first six missions under the indefinite-delivery indefinite-quantity OPOC are to be cost-type—placing cost risk on the government—while the orders for the six subsequent missions are to be firm-fixed-price type. Transition from cost-type orders to firm-fixed-price orders could help control costs and reduce the government's cost risk, but this transition remains several years away.

According to Orion officials, NASA is also implementing a batch ordering strategy of Orion missions in order to optimize cost savings. NASA plans to order a minimum of six missions under OPOC, but to date, NASA has only ordered the first three missions (Artemis III through V) with the next order of three (Artemis VI through VIII) originally planned for fiscal year 2022. Officials told us ordering in batches of three was the most cost-effective method. Additionally, Orion program officials stated that ordering in batches of three missions gives Lockheed Martin the flexibility to order parts from subcontractors in a more cost-effective manner.

According to Orion program officials, assumptions about cost savings for future Orion spacecraft production are primarily derived from the reuse of hardware. NASA plans to order new spacecraft pressure vessels for Artemis III through V and high value components, such as avionics, for Artemis II through IV and reuse these components in subsequent missions. NASA intends to use each pressure vessel on two missions and high value components on five missions. Through these efforts, NASA anticipates a potential cost savings of approximately $800 million.

Orion program officials told us that they must place the order for Orion missions VI through VIII approximately 5 years in advance of the expected Orion VI mission date to allow for sufficient time for Lockheed Martin to buy long lead materials and manufacture the spacecraft. According to the contract, NASA planned to place this order during fiscal year 2022. NASA officials explained that year was chosen because

Artemis VI was planned for August 2027 at the time of the OPOC contract award. In September 2020, NASA officials told us that they plan to delay the second order of Orion spacecraft by a year to track with the recently announced Artemis VI launch date of August 2028. We will continue to monitor the timing of this order as NASA risks prematurely committing itself to additional acquisitions before the hardware is needed if it places this order too early.

NASA Plans to Establish Baselines for Capability Upgrades Too Late and Managers Lack Robust Oversight Tools

NASA Plans to Establish Cost and Schedule Baselines for Capability Upgrades Late in Development

As NASA has already awarded long-term Artemis contracts, it must ensure that sufficient programmatic tools are in place to manage these efforts. We have previously found that NASA often lacks cost and schedule baselines needed to oversee its programs and that this contributes to poor acquisition performance. Since May 2014, we have found that there is a lack of transparency in the long-term costs of these human spaceflight programs.[22] Specifically, the EGS and SLS programs do not have a cost and schedule baseline that covers activities beyond Artemis I. In addition, the Orion program does not have a baseline beyond Artemis II. As a result, we found that NASA is planning to spend billions of dollars for missions that do not have a cost and schedule baseline against which to assess progress.

GAO's Cost Estimating and Assessment Guide, a guidebook of cost estimating leading practices developed in concert with the public and private sectors, identifies baselines as a critical means for measuring program performance over time and addresses how a baseline backed by a realistic cost estimate increases the probability of a program's success.[23] To that end, we have made recommendations in the past—and identified these recommendations as warranting priority attention—on the need for NASA to baseline these programs' costs for capabilities

[22]GAO-14-385.

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

beyond the Artemis I mission.[24] Specifically, in May 2014, we recommended that, to provide Congress with the necessary insight into program affordability, ensure its ability to effectively monitor total program costs and execution, and to facilitate investment decisions, NASA should establish separate cost and schedule baselines for each additional capability that encompass all life cycle costs. NASA partially concurred with this recommendation and expressed intention to establish these baselines when requirements for the capability upgrades were defined.

Through the course of this review, NASA informed GAO of its plans to establish separate baselines for SLS Block 1B, the Orion Docking System, Mobile Launcher 2—a $570 million effort to develop a new launch tower to accommodate the larger SLS Block 1B—and SLS Block 2. While planning to establish these baselines is a positive step, as of October 2020, NASA has not approved baselines for these efforts.

- **SLS Block 1B:** The SLS program completed the Block 1B preliminary design review in November 2016. The program is now working toward a critical design review in summer 2021, but the program has not completed a cost and schedule baseline. Program officials stated it has been too difficult to complete a baseline with the uncertainty surrounding the schedule for the first launch of Block 1B and whether that flight would be crewed or not crewed.
- **Orion Docking System:** The Orion program completed the Docking System preliminary design review in April 2020. The program is now working toward a critical design review in March 2021, but has not completed a cost and schedule baseline. Program officials stated that there has been uncertainty regarding NASA's approach in establishing a baseline for the Docking System, including whether it would be a separate baseline or amended to the existing Orion baseline. Subsequently, ESD officials told us that they have since decided to establish a separate baseline in summer 2021.
- **Mobile Launcher 2:** The EGS program is planning to complete its preliminary design review for Mobile Launcher 2 in March 2021, but officials stated that they will not establish cost and schedule baselines

[24]We send letters each year to the heads of key departments and agencies, including NASA, which give the overall status of the department's or agency's implementation of our recommendations and identify open recommendations that should be a priority for implementation. In April 2020, we sent the Administrator of NASA this year's letter, which identified seven recommendations as being a priority for implementation. See GAO, *Priority Open Recommendations: National Aeronautics and Space Administration*, GAO-20-526PR (Washington, D.C.: Apr. 23, 2020).

until the program's critical design review, planned for summer 2021. Program officials stated that establishing a Mobile Launcher 2 baseline depends heavily on getting mature SLS Block 1B requirements, and they expect to have sufficient information on requirements from SLS at the critical design review.

- **SLS Block 2:** The SLS program has not yet completed a preliminary design review for Block 2 and does not yet have a schedule for establishing cost and schedule baselines because it is still early in development.

NASA officials told us they plan to address the timing for establishing baselines for capability upgrades within existing programs—such as those discussed above—in an upcoming policy revision, but this will not be complete before 2021. While waiting for this policy update, the Human Exploration and Operations Mission Directorate has determined that it will establish baselines for these efforts, but not until the critical design reviews. This differs from the process used for other NASA acquisition programs, where the baseline is established earlier—following the preliminary design review—to ensure the project is sufficiently mature to begin phase C and the cost and schedule are adequate to enable mission success with acceptable risk.

The timeframe for establishing cost and schedule baselines for these expensive capability upgrade projects is important. By waiting to establish baselines for these efforts at the critical design review, NASA is actively working on maturing designs without agreements on the resources and timeframes needed to complete these efforts. As a result, NASA will likely be ill-equipped to evaluate the integrity of the project design and evaluate its ability to meet mission requirements with appropriate margins and acceptable risk within defined project constraints, including available resources.

Quarterly Briefings Provide Little Visibility into Planned Capability Upgrades

NASA's policy directive that outlines the agency's structure, values, management priorities, and processes requires Mission Directorates to conduct program or project reviews quarterly or as required.[25] The Human Exploration and Operations Mission Directorate conducts separate quarterly status program reviews of the SLS, EGS, and Orion programs. NASA's November 2019 guidance to the programs identifies the types of information that should be presented including a program overview, an Artemis I schedule summary, performance relative to the

[25]NASA, NASA Policy Directive, *NASA Governance and Strategic Management Handbook*, NPD 1000.0C.

critical path, top program risks, and cross program risks. In addition, the programs are to include a future missions summary to include an Artemis II schedule, a contractor discussion for those on the critical path for Artemis I or II, and risks. Programs are also required to provide an Artemis III and beyond summary.

Although quarterly reviews provide summary and related risk information, we found that the information provided to senior leaders at the quarterly reviews does not include a level of detail on the planned future capability upgrades that provides adequate insight into their cost, schedule, or technical progress. While NASA has indicated its management receives some of this information through other channels, communicating this information through the quarterly reviews is needed to ensure management receives a consistent and comprehensive assessment of how the performance of these capability upgrades may affect planning for future Artemis missions. With the focus of these reviews on delivering near-term capabilities to support the planned lunar mission in 2024, reporting for future capability upgrades—including Mobile Launcher 2, SLS Block 1B, and SLS Block 2—is subsumed in larger program briefs and not presented in detail. In addition, the Orion program has not included the Orion Docking System in the past two quarterly reviews after having preliminary design review. For example, our analysis of quarterly program status reports found that the quarterly updates to NASA leadership from November 2019 to August 2020 included no information on these capability upgrades for:

- Earned value management. This 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 objective estimates of anticipated costs at completion.
- Top project risks. Programs typically present risk charts that track the likelihood and significance of potential risks occurring and planned mitigation strategies.
- Detailed project schedules. These schedules include tracking efforts on the project's critical path—the primary schedule drivers.

Given the long history of cost growth and schedule delays with these human spaceflight programs, robust performance status updates are needed for management oversight. A principle of federal internal controls is that an agency design appropriate types of control activities to help management fulfill responsibilities and address identified risk responses. Examples of control activities include top-level reviews of actual

performance and establishment and review of performance measures and indicators.[26] It is particularly important that NASA leadership be apprised of the status of these critical capability upgrade projects as NASA is currently devoting the majority of its resources for these programs to support missions after Artemis I. For example, 92 percent of the $2.2 billion fiscal year 2021 budget request for the SLS program is for non-Artemis I activities.

Conclusions

NASA is making progress on its multibillion dollar effort to transport humans beyond low-Earth orbit, but this progress has also been accompanied by extensive cost overruns and schedule delays for the SLS, Orion, and EGS programs. NASA is also facing further risks as it begins to commit billions of dollars to the development of future capability upgrades for these programs while mission requirements remain in flux. NASA plans to improve visibility into the long-term performance of these human spaceflight programs, an important action given the significant resources NASA is dedicating to these efforts. But timeliness of completing these actions is important as well. In particular, these new development efforts require robust oversight to identify and mitigate risks, but NASA has already missed the opportunity to establish baselines at the preliminary design review for two programs, and further delays will only continue to limit their effectiveness as an oversight tool to monitor program performance. Further, little information is presented to ESD management in the quarterly program status reviews regarding program risks, contractor performance, and anticipated cost and schedule for future capabilities including the Orion Docking System, Mobile Launcher 2, SLS Block 1B, and SLS Block 2. Ensuring ESD management receives this information for future capabilities now reduces the risk of discovering challenges in these development efforts when it is too late to course correct.

Recommendations for Executive Action

We are making the following two recommendations to NASA:

We recommend that the NASA Administrator ensure that the NASA Associate Administrator for Human Exploration and Operations Mission Directorate establish cost and schedule baselines for SLS Block 1B, SLS Block 2, Mobile Launcher 2, and Orion Docking System at their

[26]GAO, *Standards for Internal Control in the Federal Government*, GAO-14-704G (Washington, D.C.: September 2014).

preliminary design reviews or as soon as practicable in advance of critical design reviews. (Recommendation 1)

We recommend that the NASA Administrator ensure that the NASA Associate Administrator for Human Exploration and Operations Mission Directorate directs the Exploration Systems Development organization to include cost, schedule, and technical performance updates for SLS Block 1B, SLS Block 2, Mobile Launcher 2, and the Orion Docking System in its quarterly program status reviews in order to maintain oversight of these development projects. (Recommendation 2)

Agency Comments and Our Evaluation

We provided a copy of this report to NASA for comment. In written comments, NASA agreed with our recommendations and estimated it would begin addressing these recommendation in the first quarter of calendar year 2021. NASA's comments are reprinted in appendix I.

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

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

W. William Russell
Director, Contracting and National Security Acquisitions

Appendix I: Comments from the National Aeronautics and Space Administration

National Aeronautics and
Space Administration

Headquarters
Washington, DC 20546-0001

November 25, 2020

Reply to Attn of: Human Exploration and Operations Mission Directorate

Mr. W. William Russell
Director, Contracting and National Acquisitions
United States Government Accountability Office
Washington, DC 20548

Dear Mr. Russell:

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to review and comment on the Government Accountability Office (GAO) draft report entitled, "NASA Human Space Exploration: Significant Investments in Future Capabilities Require Strengthened Management Oversight" (GAO-21-105), dated October 21, 2020.

Over the past year, NASA has continued to make progress in addressing concerns regarding transparency and appreciates the GAO's insights and recommendations. The GAO has accurately described the progress NASA has made and the challenges the Agency has encountered in building and testing the Orion, Space Launch System (SLS), and Exploration Ground Systems (EGS) needed to fly the Artemis missions. In particular, we agree with the GAO that the lack of a stable manifest has been a significant challenge and NASA is taking steps to address that to the greatest extent possible.

In the draft report, GAO makes two recommendations to NASA to establish baselines ahead of a key design review and improve internal reporting about capability upgrades for human space exploration programs beyond Artemis I.

Specifically, GAO recommends the following:

Recommendation 1: GAO recommends that the NASA Administrator ensure that the NASA Associate Administrator for Human Exploration and Operations Mission Directorate establish cost and schedule baselines for SLS Block 1B, SLS Block 2, Mobile Launcher 2, and the Orion Docking System at their preliminary design reviews or as soon as practicable in advance of critical design reviews.

Management's Response: NASA concurs with this recommendation. NASA intends to establish Agency Baseline Commitments (ABC) (including Joint Confidence Level analysis) as soon as practical for SLS, EGS, and Orion major capability upgrades over $250M (SLS Block 1B Exploration Upper Stage (EUS), EGS Mobile Launcher 2 (ML-2), Orion Docking

System, and SLS Block 2). The exact dates for the commitments will be determined based on appropriations and the flight manifest. Because the ML-2 ABC is largely dependent on SLS Block 1B requirements definition, NASA will establish the ML-2 ABC after the SLS EUS critical design review has been completed and the SLS EUS requirements have been incorporated into interface control documents. NASA currently estimates that the SLS Block 1B EUS, EGS ML-2, and Orion Docking System ABCs will be established by September 2021. NASA will also establish an ABC for SLS Block 2, currently targeted for use on Artemis IX, consistent with appropriations and the manifest.

Estimated Completion Date: September 30, 2021.

Recommendation 2: GAO recommends that the NASA Administrator ensure that the NASA Associate Administrator for Human Exploration and Operations Mission Directorate directs the Exploration Systems Development organization to include cost, schedule, and technical performance updates for SLS Block 1B, SLS Block 2, Mobile Launcher 2, and the Orion Docking System in its quarterly program status reviews in order to maintain oversight of these development projects.

Management's Response: NASA concurs with GAO's recommendation. As noted in the GAO report, NASA leaders do obtain information and status on future capability upgrades through channels other than the Exploration Systems Development quarterly program status reviews. Going forward, to ensure consistent reporting, NASA will include reporting on the cost, schedule, and technical performance updates of SLS, EGS, and Orion major capability upgrades over $250M in Exploration Systems Development quarterly program status reviews, beginning with the first review of 2021.

Estimated Completion Date: March 31, 2021.

We have reviewed the draft report for information that should not be publicly released. As a result of this review, we have not identified any information that should not be publicly released.

Once again, thank you for the opportunity to comment on the subject draft report. If you have any questions or require additional information, please contact Lynne Loewy on (202) 358- 0549.

Sincerely,

KATHRYN LUEDERS Digitally signed by KATHRYN LUEDERS Date: 2020.11.24 16:36:40 -05'00'

Kathryn L. Lueders
Associate Administrator for
Human Exploration and Operations

Appendix II: GAO Contact and Staff Acknowledgments

GAO Contact

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

Staff Acknowledgments

In addition to the contact named above, Molly Traci (Assistant Director), Matthew T. Crosby, Lori Fields, Laura Greifner, Erin Guinn-Villareal, Chad Johnson, Zachary Sivo, John S. Warren Jr., and Alyssa Weir made significant contributions to this report.