Report to Congressional Committees

May 2021

NASA LUNAR PROGRAMS

Significant Work Remains, Underscoring Challenges to Achieving Moon Landing in 2024

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Highlights

Highlights of GAO-21-330, a report to congressional committees

May 2021

NASA LUNAR PROGRAMS

Significant Work Remains, Underscoring Challenges to Achieving Moon Landing in 2024

Why GAO Did This Study

In March 2019, the White House directed NASA to accelerate its plans for a lunar landing by 4 years, to 2024. Accomplishing this goal will require extensive coordination across lunar programs and contractors to ensure systems operate together seamlessly and safely. In December 2019, GAO found that NASA had begun making decisions related to requirements, cost, and schedule for individual lunar programs but was behind in taking these steps for the Artemis III mission.

The House Committee on Appropriations included a provision in 2018 for GAO to review NASA's proposed lunar-focused programs. This is the second such report. This report assesses the extent to which NASA has (1) made progress on its lunar programs, including for the 2024 lunar landing goal, and (2) addressed challenges related to its management of lunar programs.

GAO analyzed lunar mission and program documents and assessed the results of a 2020 NASA-sponsored study on lunar program status. GAO interviewed NASA officials on lunar program progress and risks and on plans to address study findings.

What GAO Recommends

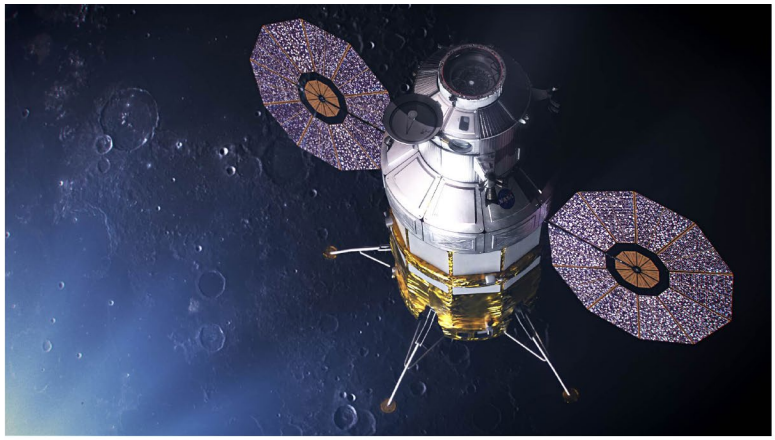
GAO is making four recommendations, including that NASA assess off-ramps for an immature Gateway technology and document the process for determining key programmatic and technical tools for the Artemis missions. NASA concurred with three of the recommendations, but did not concur with the fourth, which related to the costs included in a lunar rover's cost estimate. GAO believes this recommendation remains valid.

View GAO-21-330. For more information, contact W. William Russell at (202) 512-4841 or RussellW@gao.gov

What GAO Found

The National Aeronautics and Space Administration (NASA) has initiated eight lunar programs since 2017 to help NASA achieve its goal of returning humans to the Moon. NASA plans to conduct this mission, known as Artemis III, in 2024. NASA has made progress by completing some early lunar program development activities including initial contract awards, but an ambitious schedule decreases the likelihood of NASA achieving its goal. For example, NASA's planned pace to develop a Human Landing System, shown below, is months faster than other spaceflight programs, and a lander is inherently more complex because it supports human spaceflight.

Notional Human Landing System



Source: National Aeronautics and Space Administration. | GAO-21-330

NASA also faces technical risks. For example, the Gateway—which NASA is developing to be an outpost orbiting the Moon—will rely on power and propulsion technology that has never before been used, and contractor efforts to develop the technology are behind schedule. NASA officials said they do not have a technology backup that would meet mission requirements. GAO best practices for technology assessments state that if a technology is not adequately mature, management should assess off-ramps at milestones. For this program, off-ramps would include potentially reducing the amount of power the system is required to provide to the Gateway or reassessing the schedule to allow for more time to develop the technology. NASA risks costly design changes or delays if the agency does not identify off-ramps before committing significant resources.

NASA has not fully addressed management challenges related to its lunar programs that were identified in a 2020 NASA-sponsored study. For example, GAO found that NASA assigned Artemis mission roles and responsibilities to specific divisions in response to a study finding; however, the agency has not clearly documented how it determined what key programmatic and technical tools it plans to use to guide mission decision-making. Without doing so, NASA cannot ensure that it has the appropriate processes in place to track how the missions will achieve objectives and address risks at the mission level.

Contents

Abbreviations

AES	Advanced Exploration Systems
ESD	Exploration Systems Development
HALO	Habitation and Logistics Outpost
HEOMD	Human Exploration and Operations Mission Directorate
HLS	Human Landing System
KDP	key decision point
NASA	National Aeronautics and Space Administration
PPE	Power and Propulsion Element
PSA	Program Status Assessment
Orion	Orion Multi-Purpose Crew Vehicle
SLS	Space Launch System
SpaceX	Space Exploration Technologies Corporation
VIPER	Volatiles Investigating Polar Exploration Rover

441 G St. N.W.
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May 26, 2021

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

The Honorable Matt Cartwright
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) plans to return U.S. 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, in part, to create a sense of urgency in returning American astronauts to the Moon. To accomplish this ambitious goal, known as the Artemis III mission, NASA is working with industry to develop and acquire a Human Landing System (HLS), redesigning space suits for lunar surface operations, and planning to execute uncrewed and crewed demonstration missions of the Orion Multi-Purpose Crew Vehicle (Orion) and the Space Launch System (SLS).[1]

NASA is also developing the Gateway, which will be an outpost orbiting the Moon, to facilitate Artemis missions. NASA is designing the Gateway to act as a habitat and safe work environment for astronauts and as a communications relay between the lunar surface and the Earth. The Gateway will help support NASA's longer-term lunar exploration goals to create a sustained presence on the Moon, including to support astronauts

[1]NASA refers to its lunar efforts broadly as Artemis. The Artemis I mission is the first planned uncrewed demonstration mission of the Space Launch System, Orion Multi-Purpose Crew Vehicle, and Exploration Ground Systems programs. The Artemis II mission is the first planned crewed demonstration mission of these programs.

in carrying out lunar research and landings with extended stays on the Moon's surface.

Successfully executing the Artemis III mission will require extensive coordination across lunar programs and with a wide range of contractors to ensure systems operate together seamlessly and safely. In addition, NASA will need to ensure that the lunar programs, once in operation, will be safe for the crew and can operate in a challenging deep space environment. In December 2019, we found that NASA had begun making decisions related to requirements, cost, and schedule for individual lunar programs but was behind in taking these steps across the programs to support the overall Artemis III mission.[2] As a result, NASA risks the discovery of integration challenges and needed changes late in the development process.

GAO has designated NASA's management of acquisitions as a high-risk area for 3 decades. In our March 2021 High-Risk Series report, we reported that NASA took steps to improve transparency and monitoring of major project cost and schedules but continued to face setbacks in the cost and schedule performance of its largest programs.[3] In June 2020, the NASA Administrator approved another delay for the uncrewed test flight of SLS, Orion, and Exploration Ground Systems—known as Artemis I—due to its integration and testing schedule, among other factors. In December 2020, we found that, because of this most recent delay, NASA postponed the Artemis I mission to November 2021, 3 years past the original November 2018 baseline launch date.[4] Accompanying these delays is an estimate that the SLS and Exploration Ground Systems programs combined will exceed original development cost estimates by more than $3 billion.[5] NASA successfully completed some key test events

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

[3]GAO, *High-Risk Series: Dedicated Leadership Needed to Address Limited Progress in Most High-Risk Areas,* GAO-21-119SP (Washington, D.C.: Mar. 2, 2021).

[4]GAO, *NASA Human Space Exploration: Significant Investments in Future Capabilities Require Strengthened Management Oversight*, GAO-21-105 (Washington, D.C.: Dec. 15, 2020).

[5]The Orion program baseline cost and schedule is measured through the first crewed test flight of Orion and SLS, known as the Artemis II mission. NASA does not plan to complete revised estimates for the Orion program before fall 2021.

to evaluate these programs' readiness to support the first uncrewed test flight, but complex integration and testing remain.

The House Committee on Appropriations included a provision in its 2018 report for GAO to conduct an in-depth review of NASA's proposed lunar-focused programs.[6] This report assesses (1) the extent to which NASA has made progress on its lunar programs, including for the 2024 lunar landing goal and (2) the extent to which NASA has addressed challenges related to its management of lunar programs. This is our second report on NASA's lunar programs. We do not cover the SLS, Orion, and Exploration Ground Systems programs in depth in this report because we completed a review in December 2020 of these programs' progress towards conducting the uncrewed and crewed demonstration missions.[7]

To determine the extent to which NASA has made progress on its lunar programs, including for the 2024 lunar landing goal, we assessed NASA's lunar architecture and requirements documents, and program acquisition, budget, and requirements documents. We analyzed these documents to determine changes NASA made to its lunar plans since our December 2019 report, progress NASA made in finalizing requirements according to its policy and guidance, and areas of progress and risk to achieve the 2024 lunar landing.[8] We also analyzed program documentation and interviewed officials to determine the extent to which the programs follow NASA guidance and GAO best practices for product development, cost and schedule estimating, and technology readiness.[9] We interviewed officials within the relevant NASA mission directorates and programs to identify acquisition progress, plans to establish cost and schedule estimates, and areas of risk and mitigation plans. We also interviewed officials within the Office of the Chief Engineer's office—who are

[6]H.R. Rep. No. 115-704, at 70 (2018).

[7]GAO-21-105.

[8]GAO-20-68.

[9]GAO, *Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Program Costs*, GAO-20-195G (Washington, D.C.: Mar. 12, 2020); *Technology Readiness Assessment Guide: Technology Readiness Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects*, GAO-20-48G (Washington, D.C; Jan. 7, 2020); *Schedule Assessment Guide: Best Practices for Project Schedules,* GAO-16-89G (Washington D.C.: Dec. 22, 2015); *Best Practices: Using a Knowledge-Based Approach to Improve Weapon Acquisition*, GAO-04-386SP (Washington, D.C.: January 2004); and *Best Practices: Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes*, GAO-02-701 (Washington, D.C.: July 15, 2020).

responsible for NASA's program and project management and systems engineering policy and guidance—to determine the extent to which current NASA policy and guidance includes the requirements process that NASA uses for its lunar programs and on potential mitigation strategies related to requirements risk.

To determine the extent to which NASA has addressed challenges related to its management of lunar programs, we assessed the results of NASA's February 2020 Program Status Assessment (PSA), which identified organizational challenges within the Human Exploration and Operations Mission Directorate. The PSA assessed NASA's lunar landing plans, including how NASA organized itself to manage the Artemis III mission and NASA's approach for cross-program systems engineering. The PSA made several recommendations including that NASA designate the Artemis efforts as a formal program and that NASA establish a systems engineering and integration organization. We reviewed NASA policy and guidance and relevant federal internal control standards that related to PSA findings and recommended actions.[10] We assessed organization charts and leadership briefings and interviewed mission directorate senior leaders to determine the actions NASA planned to take to address challenges and subsequent changes in roles and responsibilities. We also interviewed the individual responsible for reviewing and assembling the overall assessment team report to get his views on the relevant PSA findings. Appendix I contains detailed information on our scope and methodology.

We conducted this performance audit from March 2020 to May 2021 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

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

Background

Key Elements of NASA's Planned Return to the Moon

NASA has initiated multiple programs since 2017 to help the agency achieve its Artemis III mission and longer-term lunar exploration goals to create a sustained lunar presence. These programs include an outpost orbiting the Moon, a landing system to put humans on the surface of the Moon, and a robotic lunar rover. NASA has used a variety of contract types under its acquisition strategies, including firm-fixed price, cost-plus incentive, and indefinite delivery/ indefinite quantity contracts.[11]

See table 1 for a description of these programs, including the acquisition strategy.

Table 1: Descriptions of NASA Lunar Programs Initiated since 2017 and Acquisition Strategy

Program or project	Description	Acquisition strategy
Gateway	The Gateway program aims to develop and build a sustainable outpost in lunar orbit. The outpost will serve as a research platform for NASA and its commercial and international partners, a staging point for human and robotic exploration in deep space, and a technology test bed for future Mars missions. NASA is planning for the Gateway to maneuver to different orbits around the Moon, which will allow access to a variety of locations on the lunar surface.[a]	The program is composed of multiple projects, which are responsible for executing portions of the Gateway mission.[b] Individual teams manage the projects, with funding and key milestones controlled at the program level. Gateway program management is responsible for ensuring the overall integration of all the individual projects.
Power and Propulsion Element (PPE)	PPE is being designed to provide the Gateway with power, communications, and the ability to change orbits, among other things.	In May 2019, NASA awarded a firm-fixed price contract to Maxar Technologies Inc. to develop and demonstrate power, propulsion, and communications capabilities. At the time of award, the total value of the contract was $375 million.
Habitation and Logistics Outpost (HALO)	HALO is being designed to provide docking ports for visiting vehicles, space for habitation and storage, and the systems to support crew on board the Gateway.	In June 2020, NASA definitized a firm-fixed price and cost plus incentive fee contract for HALO valued at $187 million to Northrop Grumman Space to develop HALO's preliminary design. NASA plans to award an additional fixed price incentive contract to the same contractor for the production of HALO.

[11]Under a firm-fixed-price contract, the price is not subject to any adjustment on the basis of the contractor's cost experience in performing the contract. FAR § 16.202-1. A cost-plus-incentive-fee contract is a cost-reimbursement contract that provides for an initially negotiated fee to be adjusted later by a formula based on the relationship of total allowable costs to total target costs. FAR § 16.304. An indefinite delivery/indefinite quantity contract provides for an indefinite quantity, within stated limits, of supplies or services during a fixed period. The government places orders for individual requirements. FAR § 16.504(a).

Program or project	Description	Acquisition strategy
Deep Space Logistics	The Deep Space Logistics project manages the Gateway Logistics Services contract, which will be used to buy services to transport cargo, science experiments, and supplies to the Gateway.	In March 2020, NASA awarded an initial firm-fixed price, indefinite delivery/indefinite quantity contract to Space Exploration Technologies Corporation (SpaceX), which guarantees the company a minimum of two logistics missions. SpaceX is responsible for building, integrating, and operating the logistics vehicle. Under the contract, NASA may award further task orders to additional logistics service providers, allowing them to compete for future missions with a total maximum value of $7 billion across all task orders.
Space suits	NASA plans to update the design of its space suits, which supply life support, including oxygen and water, among other things, to astronauts for lunar surface operations. The updates include additional protection from extreme temperatures and hazards in the lunar environment, such as dust; increased mobility; and extended service life for lunar surface operations.	NASA is developing the initial space suits used for the Artemis III mission in house, with NASA serving as the prime integrator of industry-supplied components. The project plans to deliver the suits for lunar surface operations in December 2023. NASA plans to award a contract to produce suits for later missions.
Human Landing System	The Human Landing System is to provide crew transportation from the Gateway or from Orion to the lunar surface and back and demonstrate capabilities required for deep space missions.	In May 2020, NASA awarded multiple firm-fixed price contracts to three contractors—Blue Origin Federation, Dynetics, and SpaceX—to design a lunar lander. These contracts included indefinite delivery/indefinite quantity contract line items to allow for special studies and long lead procurements. The firm-fixed price base periods for all three contractors totaled approximately $856 million. In April 2021, while this report was with NASA for review and comment, NASA announced that it selected SpaceX for an Option A contract award. This option is for the design, development, test, and evaluation, and flight demonstration of a lander for the 2024 lunar landing. The contractor may also continue to compete to develop landers for later missions. Subsequently, in April 2021, both Blue Origin Federation and Dynetics submitted a bid protest.
Commercial Lunar Payload Services	Commercial Lunar Payload Services companies are to provide NASA with end-to-end commercial payload delivery services to the surface of the Moon. The services include integrating payloads onto a robotic lander, launching the lander, and operating the lander and payloads. The payloads include science instruments and technology demonstrations that will characterize the lunar environment and inform the development of future landers and other exploration systems needed for human lunar surface exploration.	NASA awarded firm-fixed-price, multiple-award, indefinite delivery/indefinite quantity contracts to a total of 14 companies to deliver science and technology payloads to the lunar surface. According to NASA, the contract's minimum ordering value is $25,000; the maximum ordering value of the firm-fixed price contracts and task orders is $2.6 billion through 2028. As of February 2021, NASA awarded six task orders to five companies for delivery services between 2021 and 2023.

Program or project	Description	Acquisition strategy
Volatiles Investigating Polar Exploration Rover (VIPER)	VIPER is being designed to investigate volatiles—including water, carbon dioxide, and other chemicals that boil at low temperatures—at the lunar South Pole. NASA could potentially use these volatiles to support sustained human presence on the lunar surface. Scientific results from the rover that map volatiles on the lunar surface will help to inform the landing site selection for the Artemis III mission.	NASA is developing VIPER in house. In June 2020, NASA awarded a task order to Astrobotic, a Commercial Lunar Payload Services company, to deliver the rover to the lunar surface in late 2023 or early 2024. As of March 2021, the value of the task order was $226.5 million.

Source: GAO analysis of National Aeronautics and Space Administration (NASA) documents and contracts. | GAO-21-330

[a]NASA plans to initially locate the Gateway in a near rectilinear halo orbit around the Moon, which enables global lunar access and promotes access to the lunar poles.

[b]NASA calls the individual projects within the Gateway program elements. For the purpose of this report, we refer to them as projects.

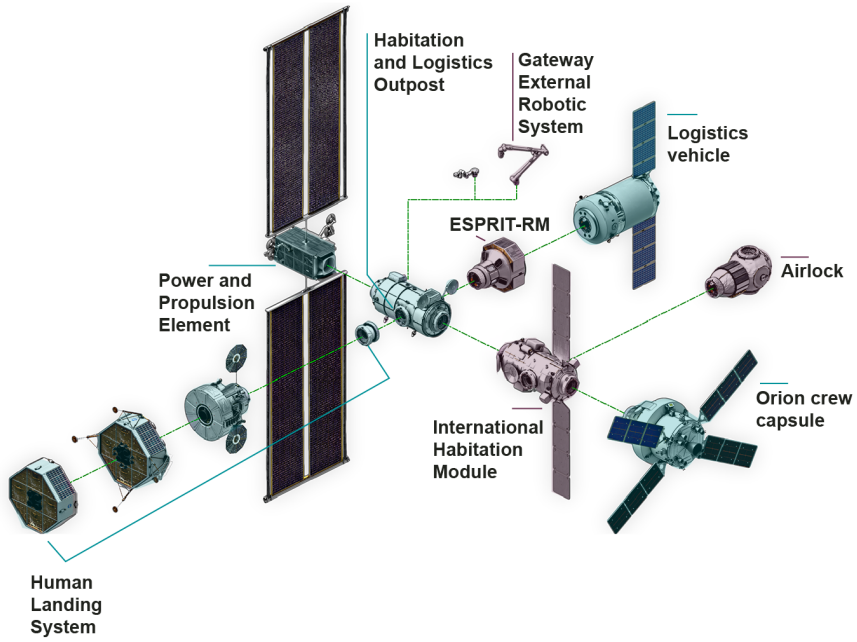
The Gateway program describes the development of the outpost in two configurations—initial and sustained.

- The initial configuration includes three projects, the Power and Propulsion Element (PPE), the Habitation and Logistics Outpost (HALO), and the Deep Space Logistics projects to support early Artemis human landing missions.
- The Gateway sustained configuration adds international partner elements to support later missions.[12]

The HALO and international habitation module will include docking ports for visiting vehicles, such as the Orion crew capsule, which will transport astronauts from Earth to the Gateway. See figure 1 for an illustration of Orion and HLS docked with the Gateway sustained configuration.

[12]In October 2020, NASA signed a memorandum of understanding with the European Space Agency for the agency's contributions, including an international habitat and refueling capability. In November and December 2020, NASA signed memoranda of understanding with the Canadian Space Agency for an external robotic system capability and with the government of Japan for contributions to the habitation and logistics resupply capabilities, respectively. Gateway program officials said that the U.S. Department of State granted NASA authorization to negotiate an agreement with the Russian Space Agency regarding participation in the Gateway. However, as of February 2021, a decision regarding Russian contribution to the Gateway has not been made.

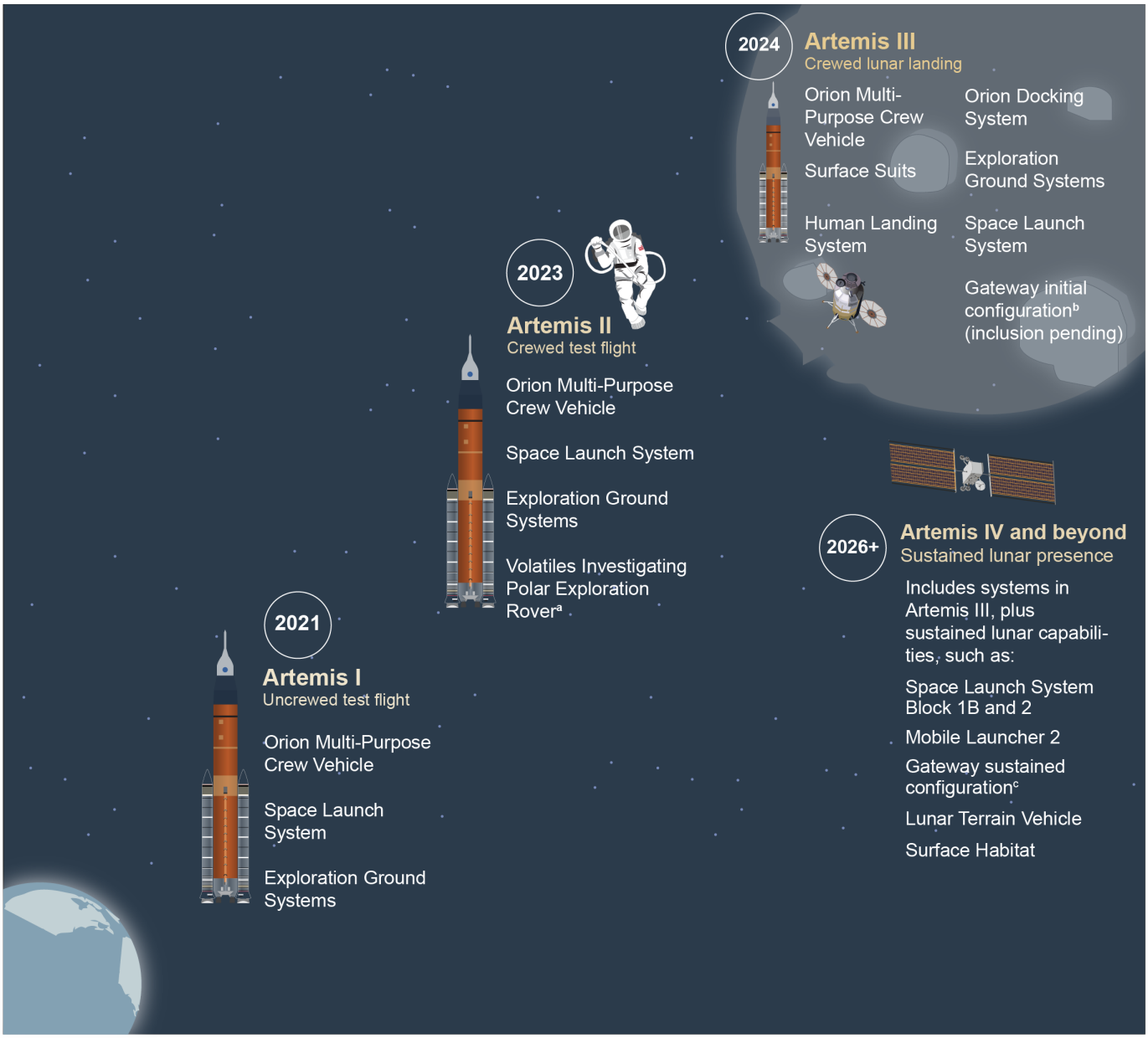
Figure 1: Illustration of the Orion Multi-Purpose Crew Vehicle and Human Landing System Docked with the Gateway Sustained Configuration



Source: National Aeronautics and Space Administration (NASA) for image.
GAO analysis of Gateway Program documentation. | GAO-21-330

In addition, NASA is continuing development of the Orion crew capsule, the SLS launch vehicle, and associated ground systems at Kennedy Space Center—known as the Exploration Ground Systems—to support transportation of humans to the Moon and beyond. Prior to the 2024 lunar landing, NASA plans to perform uncrewed and crewed test flights of Orion and SLS. NASA is also developing capability upgrades for these programs to support future missions. These include an SLS block upgrade with a more powerful upper stage and a new mobile launcher at Kennedy Space Center to transport the upgraded SLS to the launch pad. See figure 2 for the programs needed to accomplish these test flights and subsequent Artemis missions.

Figure 2: Artemis Missions and the Programs Needed to Accomplish Each Mission



Source: GAO analysis of National Aeronautics and Space Administration data (data and images). | GAO-21-330

[a]Volatiles Investigating Polar Exploration Rover is not part of the Artemis II mission, but National Aeronautics and Space Administration (NASA) plans to launch and land the rover on the lunar surface in 2023 via a contract with the Commercial Lunar Payload Services' contractor Astrobotic.

[b]The Gateway initial configuration includes the Power and Propulsion Element, Habitation and Logistics Outpost, and a Deep Space Logistics vehicle. NASA plans to determine in 2021 if the agency will use the Gateway for the Artemis III mission.

[c]The Gateway sustained configuration adds contributions from international partners, including an international habitation module, external robotic system, refueling capability, and airlock.

NASA Acquisition Life Cycle

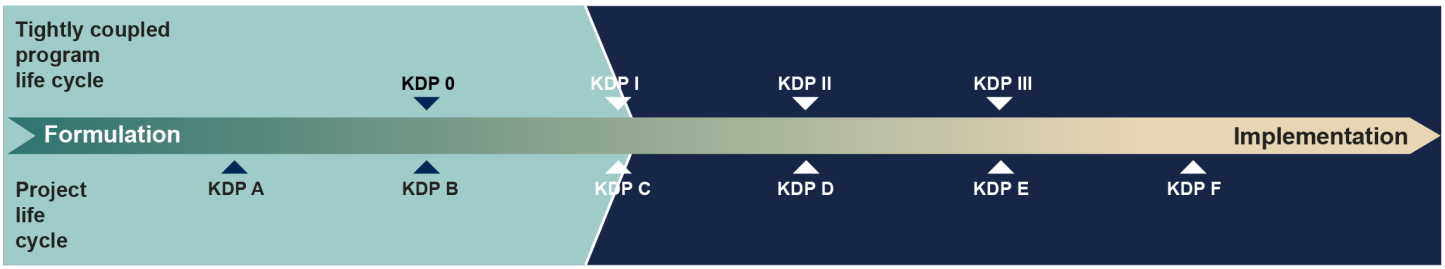
NASA initiates space flight programs and projects to accomplish its scientific or exploration goals. A NASA program has a dedicated funding profile and defined management structure, and may include several projects. Projects are specific investments under a program that have defined requirements, life-cycle costs, schedules, and their own management structure.

NASA policy states that programs and projects shall follow their appropriate life cycle. The life cycle for programs and projects consists of two phases:

1. formulation, which takes a program or project from concept to preliminary design, and
2. implementation, which includes building, launching, and operating the system, among other activities.

Senior NASA officials must approve programs and projects at milestone reviews, known as key decision points (KDP), before they can enter each new phase. NASA uses the term “tightly coupled program” to refer to a program that is composed of multiple projects that work together to complete the program’s mission. For example, the Gateway program follows the tightly coupled program acquisition life cycle because it is composed of multiple projects that are responsible for components of the Gateway. The life cycle for a single program closely resembles the life cycle for a spaceflight project. For example, the Space Launch System program follows the project acquisition life cycle because it is not composed of multiple projects. Figure 3 depicts a notional NASA life cycle for a tightly coupled program and for a project.

Figure 3: NASA's Acquisition Life Cycle for Tightly Coupled Programs and Spaceflight Projects



KDP = key decision point

Source: GAO analysis of National Aeronautics and Space Administration (NASA) policy. | GAO-21-330

The formulation phase culminates in a review at KDP I for tightly coupled programs and KDP C for projects. This decision point is also known as a confirmation review, at which cost and schedule baselines are established and documented in a decision memorandum. The decision memorandum outlines the management agreement and the agency baseline commitment. The management agreement can be viewed as a contract between the agency and the program or project manager. The program or project manager has the authority to manage the program or project within the parameters outlined in the agreement. The agency baseline commitment includes the cost and schedule baselines against which the agency's performance on a program or project may be measured.

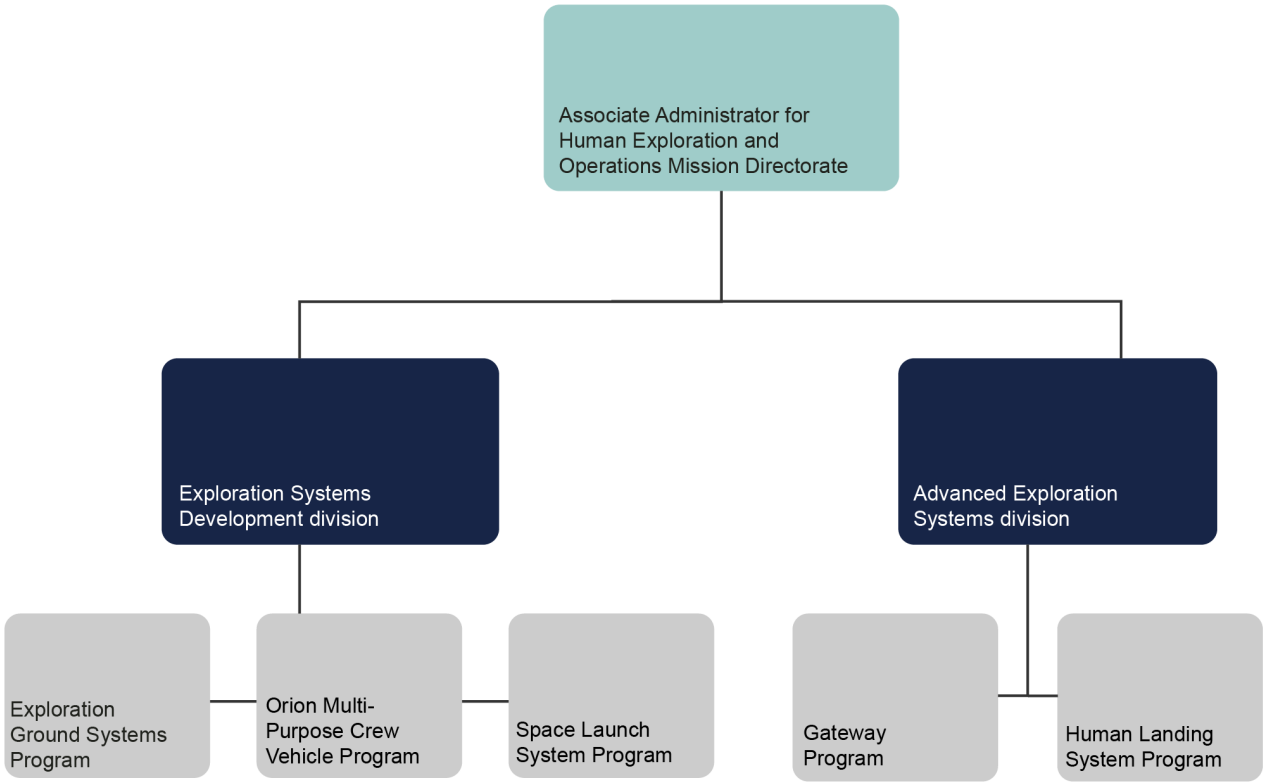
Throughout the acquisition life cycle, programs also hold reviews to assess the maturity of their systems or evaluate the readiness to move to the next phase of the life cycle. For example, near the end of the formulation phase, programs hold a preliminary design review to assess the maturity of the program's technologies and to determine if the design is mature enough to proceed with the detailed design phase.

During the implementation phase, programs hold a critical design review in order to determine if the design is stable enough to support proceeding with the final design and fabrication. After the critical design review, programs complete a system integration review to evaluate the readiness of the project and associated supporting infrastructure to begin system assembly, integration, and test.

Human Exploration and Operations Mission Directorate and 2020 Organization Assessment

NASA's Human Exploration and Operations Mission Directorate is responsible for managing programs to enable human exploration of the solar system, including to the Moon and eventually Mars. The mission directorate has two divisions primarily responsible for overseeing the programs necessary for Artemis missions—Advanced Exploration Systems (AES) and Exploration Systems Development (ESD). These divisions report to the Associate Administrator of the mission directorate. See figure 4 for a directorate organization chart that includes the programs each division is responsible for overseeing.

Figure 4: NASA's Human Exploration and Operations Mission Directorate Divisions Responsible for Lunar Programs



Source: GAO analysis of National Aeronautics and Space Administration (NASA) documentation. | GAO-21-330

In addition, NASA's Associate Administrator for the Science Mission Directorate is responsible for managing the Volatiles Investigating Polar Exploration Rover (VIPER) project and the Commercial Lunar Payload Services contracts. The Science Mission Directorate and Human

Exploration and Operations Mission Directorates coordinate on lunar surface science goals, including on how these science goals influence the Artemis III landing site selection.

In early 2020, NASA established a team to assess its lunar plans, including how the Human Exploration and Operations Mission Directorate was organized to execute these plans, in the PSA review. The purpose of the review was to assess the status of the programs and activities needed to accomplish the Artemis III mission. The PSA team identified several challenges related to how the directorate was organized to manage the integration of lunar programs to achieve the Artemis III mission. More specifically, the PSA team found that there was no Artemis organization or integrated systems engineering and integration function above the two divisions responsible for managing lunar programs—AES and ESD. The PSA also found that there were staffing shortages in key offices. We discuss these and other challenges, as well as the steps NASA has taken to address them, later in this report.

Lunar Programs Are Making Progress, but Technical and Programmatic Challenges Highlight Difficulty of Achieving Ambitious 2024 Goal

NASA's lunar programs made some progress against the agency's 2024 lunar landing goal since we last reported in December 2019. For example, NASA awarded development contracts for the Gateway and HLS programs. However, the programs face several remaining challenges due to ongoing requirements changes, the use of immature technologies, and a pending mission decision on whether NASA will use the Gateway for the 2024 lunar landing. These challenges, along with the ambitious schedule, decrease the likelihood of NASA meeting the 2024 lunar landing goal.

NASA Lunar Programs Made Progress, but Remain Early in Development with Little Information Available on Cost as 2024 Goal Approaches

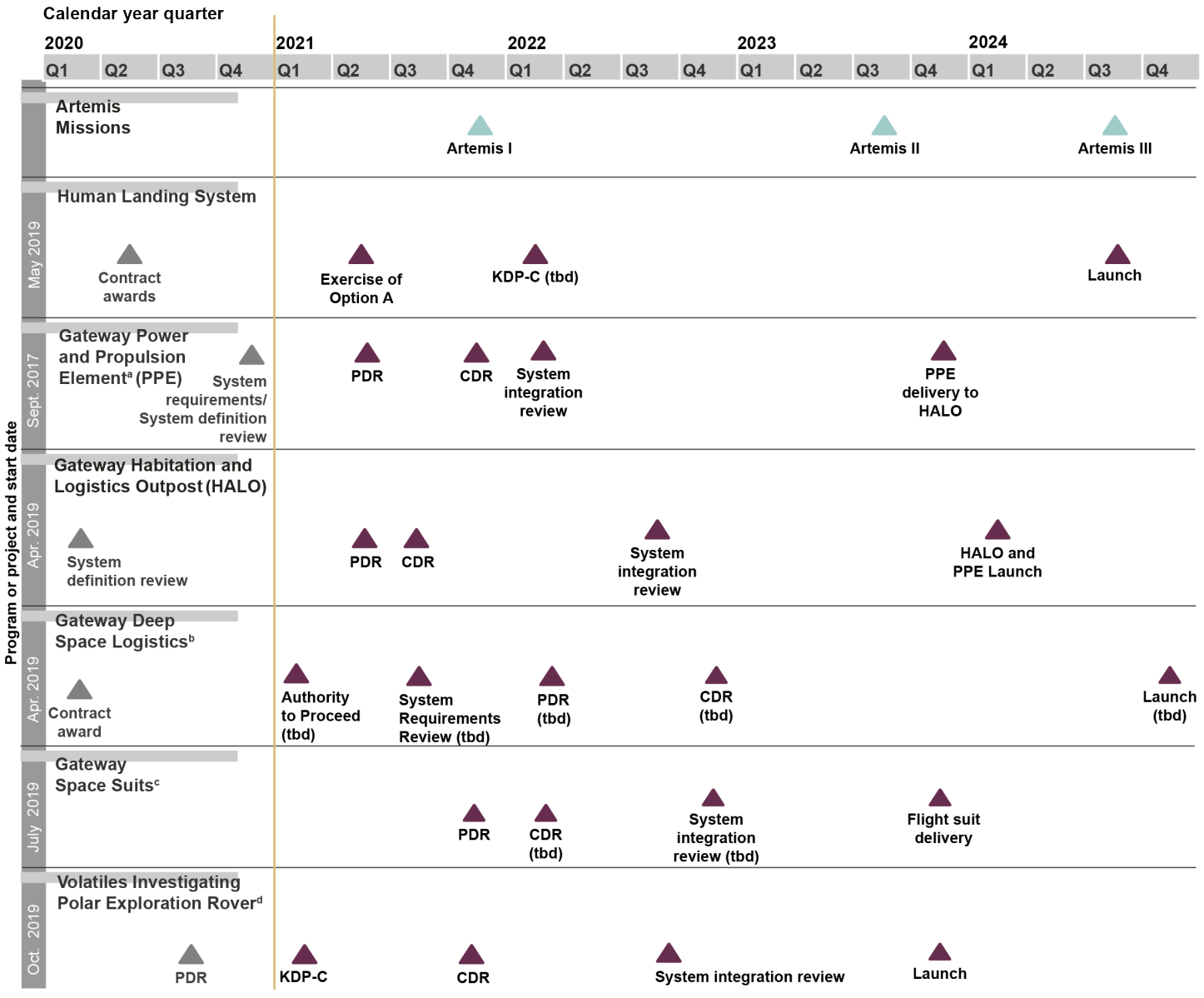
NASA made some progress against its ambitious 2024 lunar landing goal since we last reported in December 2019.[13] For example, over the last year, NASA awarded development contracts for multiple lunar programs, including for the Gateway and HLS. However, the schedule remains a top issue for the mission and requires NASA to develop programs at a rapid pace to be ready before the end of 2024. The challenging schedule is due in part to NASA having to update its lunar plans in response to the March 2019 White House directive to accelerate the lunar landing time frame. Senior NASA officials acknowledged that the 2024 lunar landing goal is ambitious; however, these officials stated that NASA's actions to build

[13]GAO-20-68.

partnerships with industry, academia, and international partners will help the agency get to the Moon quickly.

The majority of lunar programs and projects remain in the early stage of development. As a result, these programs will need to complete a significant amount of complex development between 2021 and 2024 to achieve the lunar landing goal. Figure 5 shows recent lunar program progress and key milestones remaining for the Artemis III mission.

Figure 5: Artemis III Lunar Programs' Recent Progress and Future Milestone Dates



Source: GAO analysis of National Aeronautics and Space Administration (NASA) guidance and documents. | GAO-21-330

[a]Reviews for the Gateway Power and Propulsion Element project are contractor-led reviews.

[b]Reviews for the Gateway Deep Space Logistics project are contractor-led reviews. The timing of each review is a notional schedule based on project documentation. While this report was with NASA for review and comment, agency officials told us that NASA did not provide Space Exploration

Technologies Corporation with authority to proceed on the contract in the first quarter of 2021 as planned and had not yet determined when it would do so.

[c]The Gateway Space Suits project plans to have a critical design review and system integration review, but there is no planned date. This represents a notional time frame based on project documentation.

[d]While the Volatiles Investigating Polar Exploration Rover project will not participate in the Artemis III lunar landing, it contributes to the mission by providing scientific data on how much water is on the Moon and where it is to inform the Artemis III mission landing site.

We found that the current planned pace of lunar program development from project start to launch is months faster than other major NASA projects.[14] NASA's major projects that have launched since 2010 averaged almost 87 months from project start—when NASA approves a program or project to begin the formulation phase of the acquisition process—to launch. In contrast, NASA is planning to launch the HALO module of the Gateway 57 months after project start and a human landing system 64 months after program start.[15] These projects are inherently more complex than those that averaged 87 months because they support human spaceflight. In order to meet this ambitious time frame, HLS program officials stated they have streamlined the acquisition approach—such as minimizing the set of requirements for mission success—and are leveraging industry support.

NASA also has significant work remaining to complete cost and schedule estimates for its lunar programs. In December 2019, we recommended that NASA create an Artemis III mission cost estimate.[16] NASA concurred but has not yet created this cost estimate. In February 2021, NASA officials told us that a 5-year funding plan provided to Congress in September 2020 currently serves as the agency's cost estimate through the Artemis III mission in 2024. However, this plan includes costs outside of the Artemis III mission, such as costs for the Artemis I and II missions. In addition, it does not include the funding needed for the Gateway initial configuration or costs prior to fiscal year 2021. GAO's Cost Estimating and Assessment Guide states that budget estimates, such as a 5-year funding plan, may be used to support agency decisions. However, this plan does not address our recommendation to develop an Artemis III life-

[14]GAO defines major projects as projects or programs that have an estimated life-cycle cost of over $250 million.

[15]For the HLS program, we used September 2024 as the launch date because the program is using this date as its target crew launch readiness date.

[16]GAO-20-68.

cycle cost estimate because budget estimates are not sufficient to replace a life-cycle cost estimate. Among other reasons, budget estimates often do not cover the entire life cycle of a program.[17]

Further, in response to our December 2019 recommendation, NASA stated the agency would be able to provide a preliminary cost estimate by the end of 2020. NASA officials said they could create this estimate after the agency established preliminary cost and schedule estimates for the Gateway projects at its first key decision point review and cost and schedule baselines for the HLS program, among other things. However, NASA delayed holding Gateway and HLS program-level key decision point reviews since our December 2019 report. NASA officials said they delayed these reviews to provide more accurate cost and schedule estimates. Table 2 shows the current status of lunar program and project cost estimates.

Table 2: Lunar Program and Project Cost Estimate Status as of March 2021

Program or project	Cost estimate status	Description of cost estimate progress
Human Landing System (HLS)	No preliminary estimate because NASA did not require the HLS program to develop a preliminary cost and schedule estimate prior to establishing its baseline. NASA plans to establish cost and schedule baselines for the program at an upcoming key decision point review. NASA's September 2020 Artemis Plan included a budget profile for the program between fiscal year 2021 and fiscal year 2025. The joint explanatory statement accompanying the Consolidated Appropriations Act, 2021 denoted $850 million of the $3.4 billion requested by NASA for HLS in its fiscal year 2021 President's Budget Request.	The HLS program has delayed selection of the contractor(s) that will develop a landing system for the Artemis III mission and the related exercise of option A on existing contract(s). This has resulted in a delay in the program receiving contractor data necessary to establish a program cost and schedule baseline. The HLS program plans to hold its key decision point review to establish its cost and schedule baseline 8 months from the time NASA exercises the option on the existing contract(s). As of January 2021, the program planned to hold its key decision point review in January 2022, which is 16 months later than originally planned.
Gateway	No preliminary estimate yet. The Gateway program and its four projects—Power and Propulsion Element (PPE), Habitation and Logistics Outpost (HALO), Deep Space Logistics, and Exploration Extravehicular Activity—plan to establish preliminary cost and schedule estimates at a key decision point review in April 2021.	The Gateway program delayed its first key decision point review by 9 months from July 2020 to April 2021. Gateway program officials stated that the review was pushed back to accommodate mission and design changes and to allow all Gateway projects to complete project-level reviews, among other things.

[17]GAO-20-195G.

Program or project	Cost estimate status	Description of cost estimate progress
Volatiles Investigating Polar Exploration Rover (VIPER)	NASA established cost and schedule baselines in March 2021.	The VIPER project delayed its key decision point review by 2 months, from December 2020 to February 2021. Project officials said that they delayed the review to allow more time to understand VIPER costs, including costs to address technical issues and programmatic concerns related to its lunar landing delivery service.

Source: GAO analysis of National Aeronautics and Space Administration (NASA) documents. | GAO-21-330

The VIPER project is the furthest along in establishing cost and schedule estimates because the project leveraged design work completed under a prior project called Resource Prospector, but the project's baseline does not include all relevant costs. The VIPER project's approved cost baseline is $433.5 million. Project officials stated that this did not include estimated costs from Resource Prospector or the cost to launch and land the rover.

- VIPER project officials said that they estimated the development costs under Resource Prospector at about $90.6 million. However, they did not include these costs in the VIPER cost baseline although they leveraged development work under the prior project, including work on some of the rover's instruments. Project officials stated that these costs are not included because the scope of the project has significantly changed from what was planned for Resource Prospector.
- In addition, the VIPER project plans to use a Commercial Lunar Payload Services task order to launch and land VIPER on the Moon, but NASA did not include these contract costs in the project's cost baseline. NASA initiated the Commercial Lunar Payload Services to acquire end-to-end lunar transport services from commercial entities. NASA officials said they are not managing this effort as a project or program, and as a result, there is no cost or schedule baseline for these lunar transportation services. NASA awarded a task order specifically for the delivery of VIPER to the Moon in June 2020 with an initial value of $199.5 million. As of March 2021, the total value of the task order was $226.5 million. According to project officials, the mission directorate is accounting for this $226.5 million under the Commercial Lunar Payload Services, instead of within the VIPER project cost estimate.

GAO's Cost Estimating and Assessment Guide states that life-cycle cost estimates should encompass all past, present, and future costs for a program, including costs for design, development, production, and

operations, regardless of the funding source.[18] Without including the relevant Resource Prospector costs and the costs of the Commercial Lunar Payload Services task order to launch and deliver VIPER, the VIPER project's estimate will underestimate the cost of the project. In addition, the project's estimate will not serve as a way to measure progress or track cost performance for the entirety of the project.

Significant Technical and Programmatic Challenges Remain for NASA to Meet 2024 Lunar Landing Goal

NASA's lunar programs face cost, schedule, and technical risks that highlight how difficult it will be for NASA to achieve the ambitious 2024 lunar landing goal. Specifically, NASA will need to address potential requirements gaps, technology development knowledge gaps, and a pending Artemis III mission decision that affects multiple programs.

Potential requirements gaps. In December 2019, we found that NASA identified the components of its lunar architecture—such as the Gateway and lunar landers—but it had not fully defined a system architecture or established requirements for its lunar mission.[19] NASA officials stated that delaying the definition of a system architecture and the establishment of higher-level requirements was due, in part, to NASA's acquisition approach for the lunar programs. This approach includes using service-type contracts to buy transportation services. NASA officials stated that it was important to first establish requirements for individual programs and review what contractors proposed for the Gateway and HLS and then incorporate industry input on feasible requirements. As of April 2021, the Human Exploration and Operations Mission Directorate was in the process of finalizing Artemis-level requirements, both architectural and mission level, that will be needed to fully integrate the systems and meet mission objectives.

Such an approach is a continued evolution of how NASA is approaching its major acquisitions for human spaceflight. As described in a January 2021 report by Aerospace Safety Advisory Panel—a panel that evaluates and advises NASA on safety performance—NASA is acquiring major components of it lunar mission through industry partnerships, such as the agency did for the Commercial Crew Program.[20] The panel explained that under this approach, NASA specified higher-level mission performance, safety, and key interface specifications that the contractors had to

[18]GAO-20-195G.

[19]GAO-20-68.

[20]NASA Aerospace Safety Advisory Panel, *Annual Report for 2020* (Washington, D.C.; Jan. 1, 2021).

incorporate into their designs and concept of operations but shifted significant responsibilities, such as for oversight and systems engineering, to the contractors. Although this approach was intended to foster the benefit of innovation and agility, the panel noted that it deviated from a traditional acquisition approach. NASA used a traditional acquisition approach for previous human space flight programs, such as the Orion and SLS programs, in which NASA led program management, systems engineering and integration, and operational mission design.

There are risks associated with NASA's approach of delaying the establishment of high-level requirements and its increased use of the service-type contract approach. For example, NASA has experienced cost growth due to a lack of defined high-level requirements for the Gateway program. In December 2019, we found that the PPE project finalized its requirements before the Gateway program finalized corresponding requirements, leading to potential requirements gaps between PPE and the Gateway.[21] NASA officials later confirmed the two gaps, which were related to the amount of power PPE is to provide the Gateway and PPE's ability to control the entire Gateway when in orbit. These gaps resulted in contract modifications to PPE's firm-fixed price contract, totaling $30 million to update the PPE design, such as increasing the operating voltage of PPE and adding small chemical thrusters and larger wheels to aid control. The project is planning three additional contract modifications in 2021 due to additional design changes and ongoing Gateway requirements updates that will likely further increase contract costs.

NASA officials acknowledged there is a risk of discovering additional requirements gaps due to having to reconcile requirements between the mission, system, and program levels, which can result in cost growth and schedule delays. Examples of steps NASA is taking to mitigate this risk include:

- The HLS program held reviews with each contractor 3 months after NASA authorized the contractors to start work on the base contracts to agree on a set of design and construction, safety, and health and medical standards. These standards will determine how the contractors build the landers and meet program requirements. Although not required by NASA policy, HLS program officials stated that the process to reconcile standards within this 3-month period

[21]GAO-20-68.

would reduce risk and increase the speed of decisions between NASA and the contractors to avoid ongoing requirements gaps and delays late in the acquisition life cycle.

- In addition, NASA plans to hold synchronization reviews to help ensure that requirements between mission and program levels are reconciled. We recommended in December 2019 that NASA define and determine a schedule for these reviews.[22] NASA concurred with this recommendation and plans to hold the first synchronization review in fall 2021.

NASA indicated that for future acquisitions, including subsequent Artemis missions to the Moon or to Mars, the agency plans to utilize service-type contracts. NASA officials said the approach allows for flexibility and innovation from industry partners. However, there is a risk that such approach may again result in NASA delaying the establishment of higher-level agency requirements as it obtains input from industry.

Acquisition best practices state that requirements should be clearly-defined, affordable, and informed early in the development effort.[23] Not doing so creates cost, schedule, and technical risks because requirements are not firm before entering production. Deciding how best to address requirements involves a process of assessing trade-offs before making decisions. The later the trade-offs occur, the more expensive they become to address. Likewise, we previously found that without thoroughly analyzing requirements for feasibility, development costs are impossible to estimate and are likely to grow.[24]

Officials within the Office of the Chief Engineer who are responsible for program management and systems engineering policy stated that they plan to develop a reference guide that would discuss acquisition life cycle approaches when using service-type contracting given this is a new approach for NASA and likely to be a continued acquisition strategy. These officials explained they first want to start with a reference guide and allow programs to gain some experience implementing this acquisition approach, and then determine whether there should be updates to policy and guidance. According to these officials, however,

[22]GAO-20-68.

[23]GAO-02-701.

[24]GAO, *Best Practices: Increased Focus on Requirements and Oversight Needed to Improve DOD's Acquisition Environment and Weapon System Quality*, GAO-08-294 (Washington, D.C.: Feb. 1, 2008).

they had not yet planned to include information on setting requirements for these types of contracts in the reference guide because they first wanted programs to gain implementation experience and leverage lessons learned. Officials stated that they plan to begin development of the guide in spring 2021, but did not yet have a time frame for completion of the guide. In the interim, officials said they would provide risk mitigation guidance through direct coordination with the programs. Without developing risk mitigation guidance for future acquisitions that use this contracting and requirements approach, the agency may risk cost increases and schedule delays to reconcile requirements between different levels and address any additional requirements gaps.

Technology development knowledge gaps. NASA lunar programs and projects face additional risk due to the use of immature technologies and the ambitious schedule required to develop such technologies. GAO best practices work has shown that maturing technologies to a technology readiness level 6—which includes demonstrating a representative prototype of the technology in a relevant environment that simulates the harsh conditions of space—by preliminary design review can minimize risks for the systems entering product development.[25]

To help meet the 2024 goal, NASA planned to avoid extensive technology development for its lunar landers by asking the HLS contractors to include mature technologies in their proposed designs. However, in practice, the initial HLS contractor proposals included technologies with relatively low maturity levels that will require additional time to develop or for NASA and the contractors to make a trade-off to use more mature technologies. For example, the proposed designs for the power and propulsion systems are comprised of complex, immature systems. Our analysis of HLS critical technologies data for all three contractors showed that the contractors proposed only four mature technologies out of a total of 11 critical technologies at the time of the base contract award.

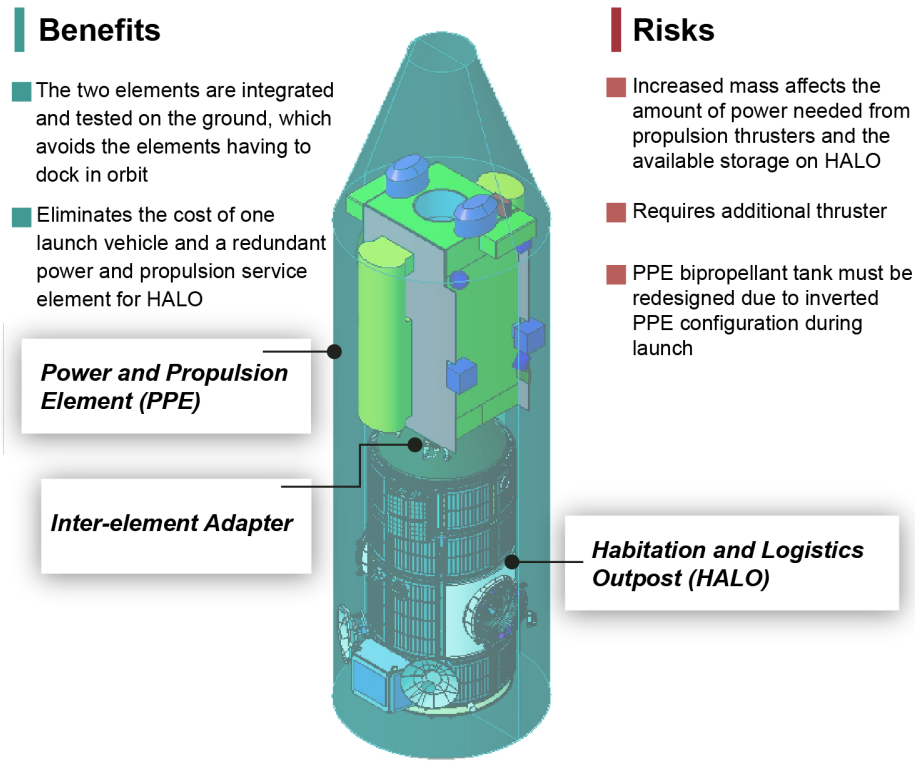
The base period contracts included a NASA review of each contractor's design relative to its initial proposal, which was intended to help the program understand design risks and each of the contractor's plans to effectively manage those risks within the ambitious schedule. In addition, NASA asked the contractors to include plans for how they will mitigate the technical and schedule risks related to lower maturity technologies in their proposals for a potential option period. According to HLS program

[25]GAO-20-48G.

officials, the contractors' designs should be at a preliminary design level maturity with technologies at a minimum technology readiness level 6, at that time.

The Gateway program also increased technical risks due to the recent decision to launch its PPE and HALO modules on the same vehicle, known as a co-manifest. Early in 2020, NASA began studying the feasibility of launching PPE and HALO together as a co-manifested vehicle after learning that launch vehicle providers may be able to develop a fairing—the part of the rocket that would encapsulate PPE and HALO during flight—that is large enough to fit both modules. Based on those studies, NASA determined the plan was feasible. See figure 6 for a representation of the co-manifested vehicle including the risks and benefits of the vehicle, according to NASA officials.

Figure 6: Representation of Co-manifested Vehicle for Two Gateway Projects and the Associated Benefits and Risks



Source: Northrop Grumman, Maxar Technologies (image) and GAO analysis of Gateway program and project documentation. | GAO-21-330

The PPE project will now need to complete two crucial PPE hardware redesigns in time for the January 2024 launch. First, because the co-manifested vehicle requires PPE to be launched inverted when compared to original designs, the project had to redesign its bipropellant tank—a dual chambered fuel system—that originally used a prior fuel system design. The PPE project finalized a contract modification to its firm-fixed price contract with Maxar in July 2020 for the redesign. Due to the complexities and time needed to manufacture the redesigned tank, the Gateway program delayed the co-manifested launch from November 2023 to January 2024.

Second, because of the increased mass of the co-manifested vehicle, the Gateway now requires PPE to use an even higher-power solar electric propulsion system than originally planned. This system includes technology for the thrusters that is not yet mature. NASA is developing the thrusters under a separate technology demonstration project managed by the Space Technology Mission Directorate. We previously found that the project experienced challenges, including both contractor performance and development challenges, which have resulted in schedule delays.[26] As a result, the PPE project does not expect the thruster technology to reach technical readiness level 6 until after the project's preliminary design review. This increases project risk of approving a design that is less likely to remain stable through production.

As a result of NASA's decision to launch PPE and HALO together as a co-manifest, NASA officials told us that using a lower-kilowatt propulsion system is no longer a back-up option if they experience delays with the solar electric propulsion system. Officials also stated that no other viable alternative currently exists. Therefore, if the thruster development is not mature when needed for integration, which is currently scheduled for August 2022, the PPE project will not be able to fulfill the current requirements for the Gateway.

GAO best practices state that, if technology is not adequately mature to transition to product development, management should assess off-ramps at the next critical decision milestone.[27] In addition, NASA policy states that, prior to entering implementation, programs should have stable requirements with appropriate margins, acceptable risk, and schedule

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

[27]GAO-20-48G.

constraints. For the PPE project, off-ramps would include determining if the project needs requirements relief prior to the project's confirmation review, planned for October 2021. NASA could also adjust the project's current launch schedule to allow for more time to develop the technology.

Due to the significant level of risk involved with the development of a high-powered solar electric propulsion system, significant design changes could result later in development if the project does not identify off-ramps prior to entering implementation or adjust the schedule to allow for more time to develop the technology. These late design changes would likely increase project cost and schedule and affect other lunar programs and projects, including HALO.

Pending Artemis III mission decision. A senior NASA official stated that NASA will likely not make a decision on whether it will use the Gateway for the Artemis III mission until summer 2021, leaving limited time to account for potential mission and program requirements changes before a 2024 launch.[28] In the meantime, the Gateway program continues to work towards the 2024 date.

According to NASA officials, the decision whether to use the Gateway in 2024 hinges on two factors: 1) Gateway program progress and risks due in part to the co-manifested launch and 2) the concept of operations for the HLS that NASA selects, which may plan to dock directly with Orion rather than with the Gateway for the Artemis III mission.[29]

The pending decision on whether NASA uses the Gateway in the mission affects mass considerations, mission communication plans, and achievement of longer-term lunar exploration goals:

- If the Gateway is not used, the Orion capsule would dock directly with HLS. Directly docking with HLS limits the cargo mass available on HLS to carry space suits and lunar science projects because the Gateway would not be available to store such items until they are needed. These mass restrictions may also limit the number of lunar

[28]The space suit project under the Gateway program plans to provide updated space suits for lunar surface operations in 2024, even if NASA determines it will not use the Gateway for the Artemis III mission.

[29]In April 2021, while a draft of this report was with NASA for review and comment, NASA announced that it selected SpaceX as the contractor to develop the lunar lander for the Artemis III mission. We were not able to assess SpaceX's planned design or concept of operations for this report.

surface activities planned. Although the HLS contractor(s) are required to meet a minimum of two space walks for the 2024 lunar landing, NASA's goal is to conduct five activities if mass allocations allow. In November 2020, space suit project officials said that the current mass of the suits, interfaces, and tools met requirements for Orion docking directly with HLS but that they were working to identify ways to lower suit mass further in case additional margin is needed later in development. For example, project officials told us they could reconfigure the suits for fewer space walks, which would reduce the amount of batteries and oxygen needed.

- Without the Gateway, NASA would need to increase its communication and navigation capabilities, such as increasing the number of lunar communications assets, according to officials responsible for NASA's space communication activities. If the Gateway is in orbit before the Artemis III mission, the Gateway could be used as a communications relay between astronauts on the lunar surface and Earth. Without the Gateway, officials stated that they would need to have additional lunar relay assets in orbit 6 to 12 months before the mission, adding to the ambitious timeline for a successful mission by the end of 2024. The officials said they are working with the human exploration and science mission directorates to understand the communication and navigation capability needs for the Artemis missions, as well as for other lunar science missions, and formulating plans for meeting those needs. For example, NASA may buy communication services from satellites already in orbit, may modify existing assets to provide more capability, or may buy an additional spacecraft for the capability.
- If the Gateway is not used, NASA will need to delay its plans to demonstrate capabilities for its longer-term lunar exploration goals. The Gateway is a central component of the agency's goals towards creating a sustainable lunar presence. According to NASA's September 2020 Artemis Plan, the purpose of the Gateway is to provide a staging point for human and robotic lunar missions and support sustainable lunar missions by the mid to late 2020s. Using the Gateway will facilitate longer expeditions on the Moon and potentially multiple trips to the lunar surface during a single mission. In addition, the Gateway will allow NASA to demonstrate how a human Mars mission may work in the future.

NASA officials stated that they need to exercise the option for the HLS program in spring 2021 to understand the mission design before making the decision on whether to use the Gateway. Pending this decision, some

uncertainty will remain as the lunar programs continue to work towards the 2024 lunar landing goal.

NASA Has Not Fully Addressed Governance, Systems Engineering, and Workforce Challenges That Affect Management of Lunar Programs

The Human Exploration and Operations Mission Directorate took some steps to address the organizational challenges identified in NASA's early 2020 assessment of the programs and activities needed to accomplish the Artemis III mission, known as the Program Status Assessment (PSA). We found, however, that the directorate (1) has not finalized documentation of Artemis roles and responsibilities, (2) has not documented the extent to which NASA plans to apply program and technical management practices and tools for managing programs to Artemis missions, and (3) is in the process of establishing an integrated systems engineering function. We also found that the directorate made progress in filling vacancies but has remaining workforce challenges.

Artemis mission roles and responsibilities. We found that the mission directorate assigned Artemis missions to specific divisions but has not yet finalized the documentation of roles, responsibilities, and authorities. For example, the directorate identified the AES division as responsible for Artemis III and beyond and the ESD division as responsible for providing the launch vehicle, crew capsule, and ground support. As of February 2021, NASA officials stated that several documents—such as an implementation plan and an AES control board charter—detail division responsibilities and the governance structure for various integration groups and control boards but remain in draft form.

This action does not directly address a PSA team finding that there was not a single, formal Artemis organization. The PSA recommended that NASA establish an Artemis manager responsible for all of the programs—including the launch vehicle, crew capsule, and landing system—required to meet the 2024 Artemis III mission and a separate manager focused on later missions. The PSA team observed that, in the absence of an Artemis manager, Artemis decision-making only came together at the directorate Associate Administrator level with no one below this level authorized to make timely programmatic decisions across the divisions. Because the directorate Associate Administrator has other responsibilities outside of the Artemis effort, NASA's reliance on this position to resolve conflicts could delay the speed of decision-making in the critical final stages of the lunar effort.

After the conclusion of the PSA, the mission directorate experienced a change in senior leadership. NASA officials stated that they decided to have the AES division responsible for the Artemis III and later missions

focused on sustainability because they were concerned an Artemis manager focused only on the 2024 landing might make trade-offs that benefited the 2024 landing but were not in the best interest of establishing a sustainable lunar presence. Further, officials stated they did not need a new office to establish accountability for the Artemis missions given that they already delineated AES and ESD's responsibilities. Officials added that they felt these actions met the intent of the PSA recommendation.

With respect to the PSA team's concern that decision-making only comes together at the directorate Associate Administrator level, NASA is establishing a process for elevating resource conflicts or trade-off decisions that span programs and divisions. The process would elevate decision-making to the directorate Associate Administrator if a joint meeting of the AES and ESD control boards is unable to reach a resolution. In addition, officials said that delegating mission responsibilities to the divisions would also help to increase the speed of decision-making. Such steps, if finalized and implemented in a timely manner, will help to alleviate the concerns raised in the PSA about timely programmatic decision-making even though NASA has chosen to not establish a separate Artemis organization.

Program and technical management practices and tools. We found that while NASA's program management and systems engineering policy and guidance do not include requirements for missions, the mission directorate plans to apply some program and technical management practices and tools found in this policy and guidance to the Artemis III mission but not other practices and tools. For example, NASA plans to create an integrated master schedule for the Artemis III mission but does not plan to hold key decision point reviews or create a program commitment agreement for the mission. A program commitment agreement is an agreement between the mission directorate and the NASA Associate Administrator that authorizes a program to move into implementation. For the Artemis III mission, the agreement could include key information to assess the overall maturity of the mission, such as the definition of the mission requirements and architecture; technical performance of lunar programs, including safety and risk factors; and mission cost and schedule estimates.

The PSA team recommended that NASA assess whether it should designate the Artemis effort a formal NASA program with the associated documentation. A PSA team member explained that the team thought this would provide more structure for tracking mission schedule performance, as well as for tracking risks and issues across the lunar programs. NASA

officials told us that they will not designate the Artemis effort as a formal program. The officials explained that they developed a list of key products and plans they will use to manage Artemis missions. These include an AES implementation plan—which would describe responsibilities for coordinating program and mission requirements, decisions, and risk, among other things—and a systems engineering master plan—which would document the technical and engineering activities conducted during the mission. However, as of February 2021, NASA has not documented the process the officials used to determine which NASA program and technical management practices and tools they plan to apply to the Artemis missions. As a result, the directorate has not addressed the PSA team's concerns that NASA is not following its own procedures for program management.

Given the complexity of the effort to ensure that multiple, extensive development efforts culminate on schedule and within cost while meeting critical safety factors, formalizing the development processes, and oversight is crucial to ensuring the efforts are properly aligned. *Standards for Internal Control in the Federal Government* state that management should design control activities—such as management reviews to track performance—to achieve objectives and address risks.[30] In addition, management designs control activities at the appropriate level within the organizational structure for the appropriate coverage of objectives and risks. Given that NASA has chosen not to designate Artemis as a formal program, which would follow NASA's program management policy, the agency lacks a finalized roadmap for how it plans to manage the effort. NASA made some progress in this regard by developing a list of key products and plans it will use to manage Artemis missions. However, without documenting its process for determining the program and technical management practices and tools the agency plans to use to manage the effort, NASA cannot ensure that it has the appropriate processes in place to track how the missions will achieve objectives and address risks at the mission level.

Integrated systems engineering function. We found that the mission directorate established a systems engineering and integration office in September 2020, but this office is not responsible for the systems engineering work related to integrating systems across divisions, including SLS, Orion, HLS, and Gateway. NASA's system engineering handbook states that activities to integrate systems throughout a system

[30]GAO-14-704G.

life cycle help to ensure that integrated system functions properly. In addition, the handbook states that a lead systems engineer typically plays a key role in verification and validation activities, balancing technical risks between systems, and the technical planning of certifications. This new directorate systems engineering and integration office does not have these responsibilities but is instead responsible for mission planning, strategy, and creating high-level requirements.

Directorate officials said they created the new directorate systems engineering and integration office partially in response to the PSA, but this office does not fully address the PSA team's recommendation. The PSA team found that the AES and ESD divisions and the lunar programs were responsible for systems engineering and integration independently and that, due to the complexity and the ambitious schedule for the Artemis III mission, this approach was not sufficient. The team recommended that the directorate establish an Artemis-level systems engineering function that is responsible for Artemis-level verification and validation, certification of flight readiness, and risk management.[31]

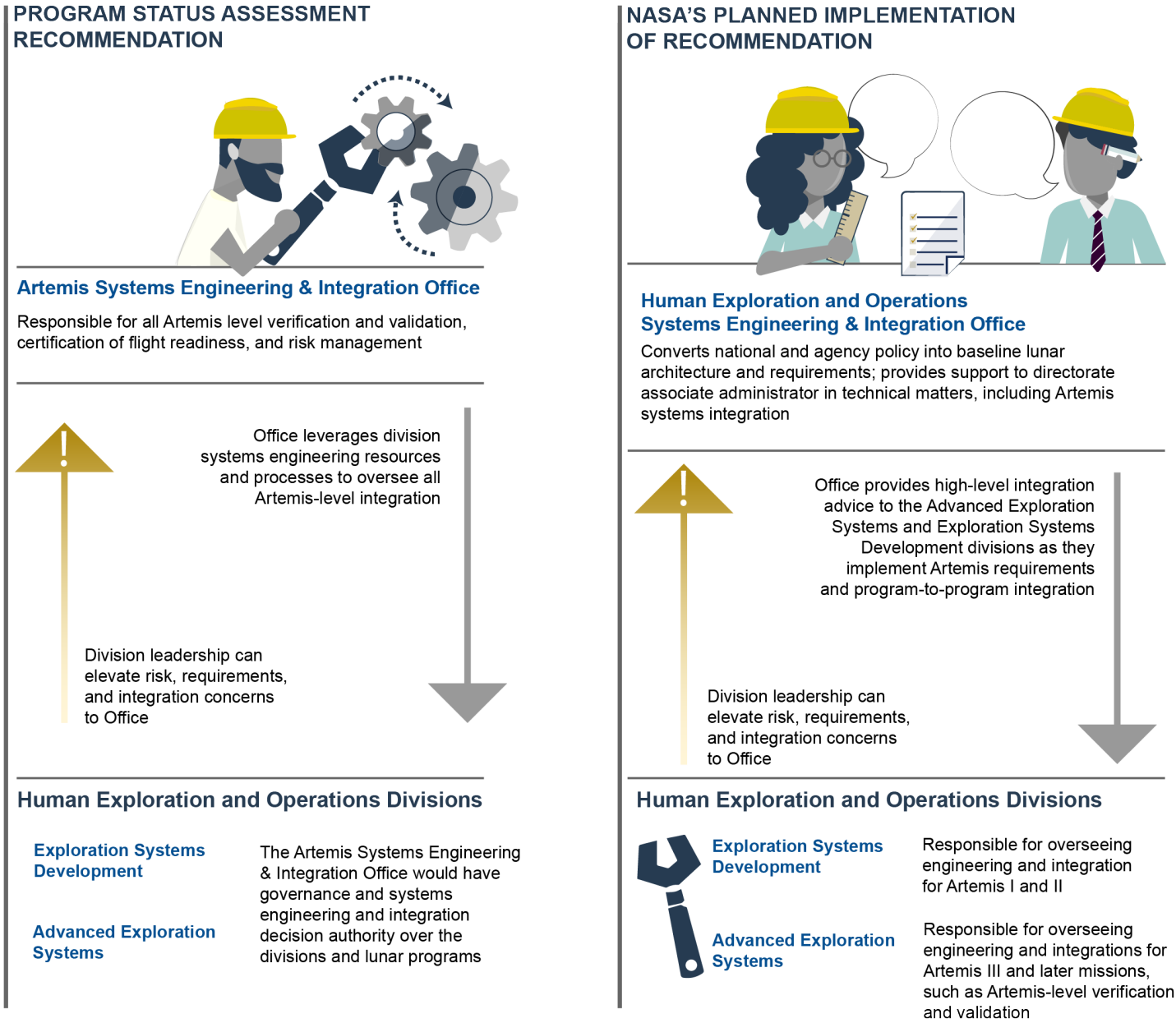
NASA officials stated they did not create an Artemis-level office above the divisions with these systems engineering and integration responsibilities because ESD already had these responsibilities for the Artemis I and II missions and NASA designated AES as having these responsibilities for the Artemis III mission and later missions. In addition, the AES division established AES-level integration teams above the flight programs that are responsible for certification of flight readiness, mission verification and validation, risk management, and for ensuring that all Artemis programs integrate together. NASA officials said that the list of key products and plans the AES division plans to develop demonstrates how NASA is leveraging the systems engineering best practices and key technical baseline products to integrate the lunar programs and overall Artemis mission. As of February 2021, the AES division was in the process of documenting its systems engineering and integration approach.

See figure 7 for a comparison of the PSA team's recommended roles and responsibilities of an Artemis systems engineering and integration

[31]Verification is the process for determining whether a product fulfills established requirements or specifications. Validation is the assessment of a planned or delivered system ability to meet the sponsor's operational need in the most realistic environment achievable through testing. Certification of flight readiness review is the process NASA uses to approve an operational mission for flight by ensuring that all flight and ground hardware, software, personnel, and procedures are operationally ready.

function and those of the new Human Exploration and Operations Mission Directorate systems engineering and integration office.

Figure 7: Comparison between Program Status Assessment Team Recommendation and NASA's Plans for Systems Engineering and Integration Roles and Responsibilities



Source: GAO analysis of National Aeronautics and Space Administration (NASA) documentation and interviews. | GAO-21-330

We and other oversight bodies have raised concerns about systems integration for the Artemis III mission.[32] For example, in January 2021, the Aerospace Safety Advisory Panel expressed concern about the Human Exploration and Operations directorate's organizational approach to systems integration in the panel's annual report. These concerns focused on a new directorate systems engineering and integration office that did not appear to provide true technical, production-level engineering integration. In January 2021, panel officials told us that integration would become more challenging with the added complexity of future missions and that they plan to continue to monitor this area as part of the panel's 2021 oversight responsibilities. Given NASA is still in the process of finalizing the AES division's systems engineering and integration plans and processes for the Artemis III and later missions, it is too soon to determine the extent to which the directorate's approach addressed the underlying concerns of the PSA team.

Workforce. We found that NASA made some progress addressing workforce challenges across the Human Exploration and Operations Mission Directorate, but the directorate has remaining challenges to address. For example, the PSA identified that the mission directorate had key personnel serving in acting roles and identified high levels of vacancies, especially in the AES division. The directorate made progress permanently filling a number of these vacancies. However, as of December 2020, the AES division still had eight out of 25 leadership positions filled in an acting capacity.

In addition, during the course of our review, the AES Acting Manager of Safety and Mission Assurance technical authority, which is an oversight position, was also serving as the Acting Manager of Safety and Mission Assurance.[33] We previously found at NASA that dual hatting personnel with both programmatic and oversight responsibilities creates an environment of competing interests where the technical authority may be subject to impairments in their ability to impartially and objectively assess

[32]GAO-20-68; NASA Aerospace Safety Advisory Panel, *Annual Report 2020* (Washington, D.C.; Jan. 1, 2021); NASA Office of Inspector General, *2020 Report on NASA's Top Management and Performance Challenges* (Washington, D.C.; Nov. 12, 2020); and NASA Advisory Council, *Human Exploration and Operations Committee Meeting Report* (Virtual Meeting; May 13-14, 2020).

[33]Safety and mission assurance technical authority personnel are responsible for ensuring, from an independent standpoint, that products and processes satisfy NASA's safety, reliability, and mission assurance policies.

the programs while at the same time having programmatic responsibilities.[34] In March 2021, while our report was with NASA for review and comment, NASA selected a new official to serve as the Manager of Safety and Mission Assurance for a one-year detail.

Conclusions

Achieving a lunar landing in 2024 is an ambitious goal, and little is known about the overall cost of NASA's efforts to do so. With just over 3 years remaining, NASA lacks insight into the cost and schedules of some of its largest lunar programs in part because some of its programs are in the early stage of development and therefore have not yet established cost and schedule estimates or baselines. And for the VIPER project, NASA did not include key costs within its baseline. The lack of key costs within the project's baseline makes it difficult for decision-makers to understand the true cost of the project and inhibits their ability to track project performance. Further, NASA's approach of contracting with commercial companies for services is a good way to foster innovation but also comes with risk. Delays in aligning higher-level program with lower-level project requirements have already led to cost growth. Ensuring NASA proactively identifies risk mitigation strategies for this contracting and requirements approach would better position future programs to avoid the same consequences.

In addition, it is important that NASA take action soon to address key technical risks in order to have enough time to develop, integrate, and test the various systems needed for the mission. NASA has an opportunity to improve its ability to meet overall goals of using the Gateway as an outpost orbiting the Moon before the Power and Propulsion Element project enters the implementation phase by ensuring that it reduces technical risk related to its solar electric propulsion system.

Effectively executing NASA's broader lunar exploration goals through Artemis missions will require an organizational structure that provides sufficient oversight of and effective coordination across lunar programs. Relying on an ad hoc process to make determinations about what program and technical management practices and tools are needed to guide mission level decisions and oversight increases the risk that NASA will discover gaps late in development.

[34]GAO-18-28.

Recommendations for Executive Action

We are making the following four recommendations to NASA.

The NASA Administrator, in coordination with the Associate Administrator for the Science Mission Directorate, should ensure the Volatiles Investigating Polar Exploration Rover (VIPER) project office includes relevant development costs from the Resource Prospector project and the cost of the Commercial Lunar Payload Services task order for the delivery of VIPER to the lunar surface into its cost baseline. (Recommendation 1)

The NASA Administrator should ensure that the NASA Office of the Chief Engineer develop guidance to mitigate risks associated with delaying the establishment of high-level requirements early in the acquisition process when using service-type contracts and incorporate it in its reference guide or a similar document. (Recommendation 2)

The NASA Administrator, in coordination with the Associate Administrator for the Human Exploration and Operations Mission Directorate, should ensure the Gateway program, in advance of the Power and Propulsion Element (PPE) project's confirmation review, assesses the solar electric propulsion thrusters' technical risks and determine whether off-ramps—such as reduced requirements for PPE—are needed or whether the project's schedule should be reassessed. (Recommendation 3)

The NASA Administrator, in coordination with the Associate Administrator for Human Exploration and Operations Mission Directorate, should ensure the Advanced Exploration Systems Division documents the process used to determine the program and technical management practices and tools that it will apply to the Artemis III and later missions, in the absence of establishing a formal Artemis program. (Recommendation 4)

Agency Comments and Our Evaluation

We provided a copy of this report to NASA for review and comment. NASA provided written comments that are reprinted in appendix II. In its response, NASA concurred with three of our four recommendations and estimated that actions to close these recommendations would occur between October 2021 and May 2022. NASA also provided technical comments that we incorporated as appropriate.

NASA did not concur with our recommendation for the VIPER project office to include relevant development costs from the Resource Prospector project and the cost of the Commercial Lunar Payload Services task order for the delivery of VIPER to the lunar surface into its cost baseline. NASA explained that it did not include development costs

for the Resource Prospector project in the baseline because VIPER's mission was significantly different, its design is much more capable, and a different mission directorate funded the project. NASA stated that development costs from the Resource Prospector project are analogous to early technology development investments, or design heritage, and the agency does not carry these costs into the cost baseline of a later mission.

However, as stated in the report, the relevant costs incurred for the VIPER project's development under the Resource Prospector project are important because they provide visibility into the total cost of developing the rover and some of its instruments. Exclusion of these costs from the project's cost baseline understates how much NASA has invested in developing a rover to map volatiles on the lunar surface. Although NASA noted that the two projects have different missions and funding sources, the VIPER project nonetheless is leveraging some of the Resource Prospector project's design work and technology development efforts.

In addition, NASA stated that it chose not to include the Commercial Lunar Payload Services task order costs in the VIPER project's cost baseline because the Commercial Lunar Payload Services initiative differs from other launch services procured for NASA missions. For example, under this initiative, NASA stated that it procured delivery of the rover as a service and the agency inherently has less ability to shape and control the launch integration and process. In summary, NASA stated that its approach will allow the performance of VIPER's direct scope, which is under the project manager's control, to be measured and tracked.

However, as noted in the report, the cost of Commercial Lunar Payload Services task order to deliver VIPER to the Moon is a key cost of the project's life cycle, even if the project is not responsible for managing the task order. While NASA included a note about the current cost of the task order in the project's key decision point-C decision memorandum, the agency does not plan to track the task order costs with the VIPER project's cost baseline or under a separate project cost baseline. As a result, NASA does not have a mechanism to track and externally report cost growth on the task order, which has already grown by $27 million, or 13.5 percent. Excluding these costs results in NASA not encompassing all past, present, and future costs for every aspect of the VIPER project, regardless of the funding source.

Therefore, we continue to believe that NASA will underestimate the cost of the VIPER project by not including the relevant Resource Prospector

costs and the costs of the Commercial Lunar Payload Services task order to launch and deliver VIPER.

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 https://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 key contributions to this report are listed in appendix III.

W. William Russell
Director, Contracting and National Security Acquisitions

Appendix I: Objectives, Scope, and Methodology

To determine the extent to which the National Aeronautics and Space Administration (NASA) has made progress on its lunar programs including for the 2024 lunar landing goal, we assessed NASA's lunar architecture and requirements documents and program acquisition, budget, and requirements documents. We analyzed these documents to determine changes NASA made to its lunar plans since our December 2019 report, progress NASA made in finalizing requirements according to its policy and guidance, and areas of progress and risk to achieve the 2024 lunar landing.[1] We included the Space Launch System (SLS), Orion Multi-Purpose Crew Vehicle (Orion), and Exploration Ground Systems programs as part of lunar architecture. We have a separate body of work that reviews these programs' progress towards conducting the uncrewed and crewed demonstration missions.[2]

To examine the planned development time frames for the Gateway and the Human Landing System (HLS) programs relative to time frames for other major projects, we calculated the number of months from program start to completion for these programs.[3] We also calculated the time frames for major projects that were included in our assessment of major project reports and launched between 2010 and 2020.

We analyzed program documentation and interviewed officials to determine the extent to which the programs are following NASA guidance

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

[2]GAO, *NASA Human Space Exploration: Significant Investments in Future Capabilities Require Strengthened Management Oversight,* GAO-21-105 (Washington, D.C.: Dec. 15, 2020); *NASA Human Space Exploration: Persistent Delays and Cost Growth Reinforce Concerns over Management of Programs*, GAO-19-377 (Washington, D.C.: June 19, 2019); *NASA Human Space Exploration: Integration Approach Presents Challenges to Oversight and Independence,* GAO-18-28 (Washington, D.C.: Oct.19, 2017); *NASA Human Space Exploration: Delay Likely for First Exploration Mission,* GAO-17-414 (Washington, D.C.: Apr. 27, 2017); *Orion Multi-Purpose Crew Vehicle: Action Needed to Improve Visibility into Cost, Schedule, and Capacity to Resolve Technical Challenges*, GAO-16-620 (Washington, D.C.: July 27, 2016); *NASA Human Space Exploration: Opportunity Nears to Reassess Launch Vehicle and Ground Systems Cost and Schedule,* GAO-16-612 (Washington, D.C.: July 27, 2016); *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 *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).

[3]For the Gateway program, we used the start and launch dates of the Habitation and Logistics Outpost (HALO) project. The HALO project office is responsible for overseeing the integration of the Gateway initial configuration.

and GAO best practices for product development, cost and schedule estimating, and technology readiness.[4] We interviewed officials within the relevant NASA mission directorates and programs, including the HLS and Gateway programs and the Volatiles Investigating Polar Exploration Rover (VIPER) project, to identify acquisition progress, plans to establish cost and schedule estimates, and areas of risk and mitigation plans. We interviewed officials within the Space Communication and Navigation division to determine NASA's plans for communications between the Earth and crew on the lunar surface. We also interviewed officials within the Office of the Chief Engineer's office—who are responsible for NASA's program and project management and systems engineering policy and guidance—to determine the extent to which current NASA policy and guidance includes the requirements process that NASA uses for its lunar programs and mitigation strategies related to requirements risk.

To determine the extent to which NASA addressed challenges related to its management of lunar programs, we assessed the results of NASA's February 2020 Program Status Assessment (PSA), which identified challenges within the Human Exploration and Operations Mission Directorate. The PSA assessed NASA's lunar landing plans, including how NASA organized itself to manage the Artemis III mission and NASA's approach for cross-program systems engineering. The PSA team was comprised of NASA personnel and outside aerospace subject-matter experts. Members of the PSA team examined management and integration across programs, schedule risks, technical risks, systems engineering and integration, and test program thoroughness.

We reviewed the assessment's findings in the areas of program- or system-level schedule and technical risk and test program thoroughness to determine whether these findings included challenges related to organization and systems engineering. We only included findings that included such challenges in our analysis. The PSA made several

[4]GAO, *Best Practices: Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes*, GAO-02-701 (Washington, D.C.: July 15, 2020); *Best Practices: Using a Knowledge-Based Approach to Improve Weapon Acquisition*, GAO-04-386SP (Washington, D.C.: January 2004); *Schedule Assessment Guide: Best Practices for Project Schedules,* GAO-16-89G (Washington D.C.: Dec. 22, 2015); *Technology Readiness Assessment Guide: Technology Readiness Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects*, GAO-20-48G (Washington, D.C; Jan. 7, 2020); and *Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Program Costs*, GAO-20-195G (Washington, D.C.: Mar. 12, 2020).

recommendations, including that NASA designate the Artemis efforts as a formal program and that NASA establish a systems engineering and integration organization. We reviewed NASA policy and guidance and relevant federal internal control standards that related to PSA findings and recommended actions.[5] We assessed organization charts and leadership briefings, and we interviewed mission directorate senior leaders to determine the actions NASA planned to take to address identified challenges and subsequent changes in roles and responsibilities. We interviewed the individual responsible for reviewing and assembling the overall assessment team report to get his views on the relevant PSA findings. We also interviewed the chair of the Aerospace Safety Advisory Panel to discuss the panel's concerns related to the mission directorate's plans for systems engineering and integration of the lunar programs.

We determined that internal controls were significant to this review. Specifically, we determined the risk assessment, control activities, and information and communication components of federal standards for internal control were applicable to objectives 1 and 2. To evaluate NASA's control activities, including the principle that management should design control activities to achieve objectives and respond to risks and risk assessment approaches, we reviewed lunar program and division documentation on risks and mitigation approaches, and we interviewed NASA officials on responsibilities for identifying and managing cross-program risks. For the information and communication component, we determined the principles that management should use and should internally and externally communicate quality information to achieve an entity's objectives were applicable. To evaluate this control, we assessed lunar program and division documentation on lunar program progress, requirements, and memoranda for organizational changes, as well as interviewed senior directorate officials and program and project managers to determine how they communicated information.

We also determined the control environment component was applicable to objective 2. We compared this control against the findings in the PSA related to organization and cross-program systems engineering. To evaluate NASA's control environment for the principle that management should establish an organizational structure, assign responsibility, and delegate authority to achieve the entity's objectives, we assessed Human

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

Exploration and Operations Mission Directorate organizational charts and memoranda approving changes to the organization, and interviewed senior mission directorate leaders.

We conducted this performance audit from March 2020 to May 2021 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Comments from the National Aeronautics and Space Administration

National Aeronautics and
Space Administration

Mary W. Jackson NASA Headquarters
Washington, DC 20546-0001

April 27, 2021

Reply to Attn of: Human Exploration and Operations Mission Directorate

Mr. W. William Russell
Director
Contracting and National Security 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 Lunar Programs: Significant Work Remains, Underscoring Challenges to Achieving Moon Landing in 2024" (GAO-21-330, 104185), dated March 23, 2021.

In the draft report, GAO makes four recommendations to NASA designed to assess the extent to which NASA has made progress on its lunar programs, including the 2024 lunar landing goal, and addressed challenges related to its management of lunar programs.

Specifically, GAO recommends the following:

Recommendation 1: The NASA Administrator, in coordination with the Associate Administrator for the Science Mission Directorate (SMD), should ensure the Volatiles Investigating Polar Exploration Rover (VIPER) project office includes relevant development costs from the Resource Prospector project and the cost of the Commercial Lunar Payload Services [CLPS] task order for the delivery of VIPER to the lunar surface into its cost baseline.

Management's Response: Non-Concur. The VIPER mission was confirmed to enter the development phase on February 23, 2021, at a total life-cycle cost of $433.5M. This amount is reported as the Agency Baseline Commitment (ABC) and includes the full development and operations costs for VIPER. As GAO noted, this amount does not include early technology development investments made by NASA, nor does it include the CLPS delivery costs. The NASA ABC for VIPER includes only costs that are managed by the VIPER project which is, therefore, accountable for meeting the project budget and schedule commitments.

The VIPER mission, implemented within SMD, is a significantly different and much more capable design than the Resource Prospector (RP) concept which evolved, over time, under the Human Exploration and Operations Mission Directorate, Space Technology Mission

Directorate, and Office of the Chief Technologist. Development costs from RP are analogous to early technology development investments which typically precede our missions. Costs for early technology development, and for prior flights of instruments, spacecraft bus design, antennae or lander designs, etc., often referred to as design heritage, are not carried into the baseline cost of a later mission.

NASA's CLPS initiative represents an innovative approach to delivering science and technology payloads to the Moon and is not directly analogous to other launch services procured by NASA for SMD missions. NASA's technical project management control over the newly developed CLPS-provided lunar surface delivery is significantly different from standard launches as procured by NASA's Launch Service Program; with CLPS, NASA procures the surface delivery as a service and inherently has less ability to shape and control the launch integration and process. In addition, the CLPS task orders (TO) are not managed by the delivered payload(s) teams, such as VIPER, under the Planetary Science Division's management. Every CLPS TO is managed by the CLPS project office at the Johnson Space Center (JSC) for the SMD Deputy Associate Administrator for Exploration. CLPS TOs often cover launch and delivery services for multiple payloads at a time, and the cost of the TO cannot be accurately allocated to individual payloads. For these reasons, SMD is not including the CLPS cost in the Project ABC.

NASA is transparent that the CLPS delivery costs are in addition to the VIPER ABC and required to achieve mission success. The VIPER payload will be accommodated on CLPS TO 20A, which contracts Astrobotic to deliver the VIPER rover. This is clearly documented in VIPER's Key Decision Point-C Decision Memorandum, acknowledging the CLPS TO cost to deliver VIPER as $226.5M above VIPER's cost of $433.5M.

The absence of RP development and CLPS delivery costs from VIPER's baseline cost will not deter or prohibit measuring VIPER's progress and tracking cost performance. On the contrary, it will allow the performance of VIPER's direct scope, which is under the Project Manager's control, to be measured and tracked.

Estimated Completion Date: N/A.

Recommendation 2: The NASA Administrator should ensure that the NASA Office of the Chief Engineer develop guidance to mitigate risks associated with delaying the establishment of high-level requirements early in the acquisition process when using service-type contracts and incorporate it in its reference guide or a similar document.

Management's Response: NASA concurs with the recommendation. The Office of the Chief Engineer plans to develop the guide.

Estimated Completion Date: May 2022.

Recommendation 3: The NASA Administrator, in coordination with the Associate Administrator for the Human Exploration and Operations Mission Directorate, should ensure the Gateway program, in advance of the Power and Propulsion Element (PPE) project's confirmation review, assesses the solar electric propulsion thrusters' technical risks and

determine whether off-ramps - such as reduced requirements for PPE - are needed or whether the project's schedule should be reassessed.

Management's Response: NASA concurs with the recommendation. NASA insight/oversight of the Solar Electric Propulsion (SEP) Advanced Electric Propulsion System (AEPS) contract includes technical risk management. The Gateway Power and Propulsion Element (PPE) will assess the AEPS Thruster technical risk and identify possible off-ramps (including, but not limited to, requirements relief or schedule adjustment) and present those to the Gateway Program for further assessment with NASA management.

Estimated Completion Date: Stated activity to be completed prior to PPE Preliminary Design Review closeout in October 2021.

Recommendation 4: The NASA Administrator, in coordination with the Associate Administrator for Human Exploration and Operations Mission Directorate, should ensure the Advanced Exploration Systems Division documents the process used to determine the program and technical management practices and tools that it will apply to the Artemis III and later missions, in the absence of establishing a formal Artemis program.

Management's Response: NASA concurs that, as Artemis III and subsequent missions are considered individual missions and are, therefore, not directly governed by Agency Program guidance documents, it is critical to document the process for how the Advanced Exploration Systems (AES) Division will manage and integrate the programs involved to successfully complete those missions and also document the programmatic and technical management practices and tools that will be applied. NASA will provide documentation of the key practices, tools, and resulting products used for the integration and conduct of the Artemis III and subsequent missions. The evidence of the enacting of this recommendation will be the completion of the first AES integrated synchronization review, planned for fall 2021.

Estimated Completion Date: November 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 Kelly O'Rourke on (202) 358-1635.

Sincerely,

KATHRYN LUEDERS Digitally signed by KATHRYN LUEDERS Date: 2021.04.29 17:02:39 -04'00'

Kathryn L. Lueders
Associate Administrator
for Human Explorations and Operations

RALPH ROE Digitally signed by RALPH ROE Date: 2021.04.27 16:16:45 -04'00'

Ralph R. Roe Jr.
NASA Chief Engineer

Sandra Connelly

Digitally signed by Sandra Connelly
Date: 2021.04.26 16:22:31 -04'00'

Thomas Zurbuchen
Associate Administrator
for Science Mission Directorate

Appendix III: GAO Contact and Staff Acknowledgments

GAO Contact

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

Staff Acknowledgments

In addition to the contact named above, Molly Traci (Assistant Director), Lorraine Ettaro, Laura Greifner, Erin Kennedy, Jason Lee (Assistant Director), Jonathan Munetz, Jeanine Navarrete, Sylvia Schatz, Alyssa Weir, Robin Wilson, and Lauren Wright made key contributions to this report.

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