United States Government Accountability Office

Report to Congressional Committees

December 2019

NASA LUNAR PROGRAMS

Opportunities Exist to Strengthen Analyses and Plans for Moon Landing

GAO-20-68

December 2019

NASA LUNAR PROGRAMS

Opportunities Exist to Strengthen Analyses and Plans for Moon Landing

GAO Highlights

Highlights of GAO-20-68, a report to congressional committees

Why GAO Did This Study

In March 2019, the White House directed NASA to accelerate its plans to return humans to the moon by 4 years, to 2024. To accomplish a lunar landing, NASA is developing programs including a small platform in lunar orbit, known as Gateway, and a lunar lander. NASA plans to use the Space Launch System and Orion crew capsule—two programs with a history of cost growth and schedule delays—to launch and transport crew to Gateway.

The House Committee on Appropriations included a provision in its 2018 report for GAO to review NASA's proposed lunar-focused programs, including the Gateway program. GAO's report assesses (1) how NASA updated its lunar plans to support the accelerated 2024 landing timeline; (2) the extent to which NASA has made initial decisions about requirements, cost, and schedule for its lunar mission and programs; and (3) the extent to which NASA analyzed alternatives for its lunar plans, including the Gateway program. GAO analyzed NASA lunar mission and program documents, assessed NASA studies that informed NASA's lunar plans, and interviewed NASA officials.

What GAO Recommends

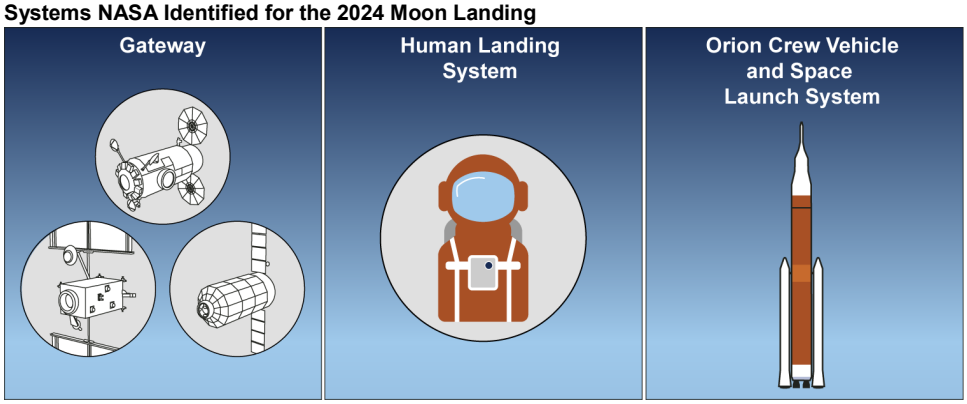
GAO is making a total of 6 recommendations to NASA, including to define and schedule reviews that align requirements across lunar programs; create a cost estimate for the first lunar mission; and commit to a completion date and finalize a cohesive document outlining the rationale for selecting its current lunar plans. NASA concurred with the recommendations made in this report.

View GAO-20-68. For more information, contact Cristina Chaplain at (202) 512-4841 or chaplainc@gao.gov.

What GAO Found

To support accelerated plans to land astronauts on the moon by 2024—four years earlier than planned—the National Aeronautics and Space Administration (NASA) quickly refocused its acquisition plans. In particular, NASA separated its lunar plans into two phases, with the first phase focused on the systems NASA identified to support the new timeline (see figure). One system, Gateway, includes three components—power and propulsion, habitation, and logistics—to form a small platform in lunar orbit.

Systems NASA Identified for the 2024 Moon Landing



Source: National Aeronautics and Space Administration (NASA). | GAO-20-68

NASA has begun making decisions related to requirements, cost, and schedule for programs, but is behind in taking these steps for the whole lunar mission:

- NASA risks the discovery of integration challenges and needed changes late in the development process because it established some requirements for individual lunar programs before finalizing requirements for the overall lunar mission. NASA plans to take steps to mitigate this risk, such as by holding reviews to ensure that requirements align across programs, but has not yet defined these reviews or determined when they would occur.
- NASA has made some decisions that will increase visibility into the costs and schedules for individual lunar programs, but does not plan to develop a cost estimate for the first mission. Cost estimates provide management with critical cost-risk information to improve control of resources. Without a cost estimate for this mission, Congress will not have insight into affordability and NASA will not have insight into monitoring total mission costs.

NASA conducted studies to inform its lunar plans, but did not fully assess a range of alternatives to these plans. GAO best practices state that analyzing alternatives provides a framework to help ensure that entities consistently and reliably select the alternative that best meets the mission need and justify agency decisions. Given NASA's schedule, conducting this analysis is no longer viable. Instead, NASA intends to create a summary of the studies that informed its lunar plans. However, it has not committed to a completion date. Without a documented rationale, NASA is ill-positioned to effectively communicate its decisions to stakeholders and facilitate a better understanding of its plans.

Contents

Abbreviations

HEOMD	Human Exploration and Operations Mission Directorate
JCL	Joint Cost and Schedule Confidence Level
KDP	Key Decision Point
NASA	National Aeronautics and Space Administration
NextSTEP	Next Space Technologies for Exploration Partnerships
PPE	Power and Propulsion Element
Orion	Orion Multi-Purpose Crew Vehicle
SLS	Space Launch System

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
441 G St. N.W.
Washington, DC 20548

December 19, 2019

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

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

The National Aeronautics and Space Administration (NASA) 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 accelerated mission, known as Artemis III, NASA plans to develop a small platform in lunar orbit called Gateway, acquire a Human Landing System, and execute uncrewed and crewed demonstration missions of the Orion Multi-Purpose Crew Vehicle (Orion) and the Space Launch System (SLS).[1] NASA plans to rely on SLS to launch and transport crew in the Orion crew capsule—two programs that we have found have a history of cost growth and schedule delays—to support a lunar landing.[2]

[1]NASA refers to its lunar efforts more broadly as the Artemis program. 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.

[2]GAO, *NASA: Assessments of Major Projects*, GAO-19-262SP (Washington, D.C.: May 30, 2019) and *NASA Human Space Exploration: Persistent Delays and Cost Growth Reinforce Concerns over Management of Programs*, GAO-19-377 (Washington, D.C.: Jun.19, 2019).

Each of these human spaceflight programs represents a large, complex technical endeavor that will require sound programmatic decision-making. Achieving the Artemis III mission will also require extensive coordination with a wide range of contractors to ensure systems operate together seamlessly and safely. For example, NASA will need to ensure that the lunar programs, once in operation, will be safe for crew and can operate in a challenging deep space environment.

GAO has designated NASA's management of acquisitions as a high-risk area for almost three decades. In our March 2019 high-risk report, we reported there was a lack of transparency in NASA's major project cost and schedules, especially for its human spaceflight programs.[3] We reported that the agency has not taken action on several recommendations related to understanding the long-term costs of its human exploration programs. For example, SLS and its associated ground systems, Exploration Ground Systems, do not have cost and schedule baselines that cover activities beyond the first planned uncrewed flight, and Orion does not have a baseline beyond the second planned crewed flight. We have previously reported that without transparency into these estimates, NASA does not have the data to assess long-term affordability and it may be difficult for Congress to make informed budgetary decisions.[4]

The House Committee on Appropriations included a provision in its 2018 report for GAO to review NASA's proposed lunar-focused programs, which includes the Gateway program.[5] Our report assesses (1) how NASA updated its lunar plans to support the accelerated 2024 lunar landing timeline; (2) the extent to which NASA has established requirements for its lunar mission and programs; (3) the extent to which NASA has made initial decisions about cost and schedule estimating for its lunar mission and programs; and (4) the extent to which NASA analyzed alternatives for the lunar architecture, including the Gateway program. This is our first report on NASA's lunar programs. We plan to

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

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

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

conduct additional work in this area, which may focus on specific programs or topics, such as safety.

To assess how NASA updated its lunar plans to support the accelerated lunar landing timeline, we analyzed NASA program acquisition, budget, requirements, and lunar architecture documents. The lunar architecture refers to programs NASA plans to use to achieve its lunar landing mission, as well as the dependencies and interfaces between these programs. We analyzed these documents to determine which programs are part of the architecture, the status and planned acquisition strategy of those programs, and changes that NASA made to the architecture and to programs after NASA received White House direction in March 2019 to accelerate its lunar landing timeline. We also interviewed officials within the relevant NASA mission directorates and programs.

To assess the extent to which NASA has established requirements for its lunar mission and programs, we assessed lunar architecture and program requirements documents. We compared NASA's plans to set requirements with the process outlined in NASA policy and guidance. We also analyzed these documents to determine the extent to which NASA has defined its architecture. We interviewed officials within the relevant NASA mission directorates and the Gateway and Human Landing System program offices to discuss the programs included in the lunar architecture and the status of establishing requirements. We met with officials within the Advanced Exploration Systems organization to discuss the status of finalizing documents that define the lunar architecture and top-level requirements. We also interviewed officials within the Office of the Chief Engineer who are responsible for relevant NASA policies and guidance.

To assess the extent to which NASA has made initial decisions about cost and schedule estimating for its lunar mission and programs, we compared NASA plans to develop cost estimates and schedules with NASA policy and guidance. Further, we conducted a more in-depth look at the Gateway program's acquisition plans because it is furthest along in the acquisition lifecycle when compared to the other lunar programs, and is a key program within the lunar architecture.[6] We analyzed the Gateway program and project acquisition and milestone documentation, and compared Gateway plans against NASA systems engineering and

[6]The Gateway program is furthest along because NASA started work on the first project of the program under a prior human spaceflight effort.

program and project management policies and guidance to determine the extent to which the program is tailoring, or modifying, NASA policies and guidance. We interviewed officials within the Human Exploration and Operations Mission Directorate (HEOMD) and the Gateway and Human Landing System program offices to understand NASA's initial decisions on developing cost and schedule estimates for the lunar mission and programs and the status of making these decisions. We also interviewed officials within the Office of the Chief Engineer and Office of the Chief Financial Officer who are responsible for NASA's policies and guidance on cost and schedule estimating.

To assess the extent to which NASA analyzed alternatives for the lunar architecture, including the Gateway program, we reviewed NASA systems engineering and program and project management policies and guidance to determine what requirements existed for analyzing alternatives, if any. We used GAO best practices to identify the benefits of assessing alternatives.[7] We analyzed trade studies, briefings, white papers, and other assessments provided to us by NASA to determine the extent to which NASA analyzed alternatives for the lunar architecture. We also interviewed HEOMD officials on the purpose of these trade studies, briefings, white papers, and other assessments and officials within the Office of the Chief Engineer and Office of the Chief Financial Officer who are responsible for NASA policies and guidance related to assessing alternatives.

We conducted this performance audit from January 2019 to December 2019 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.

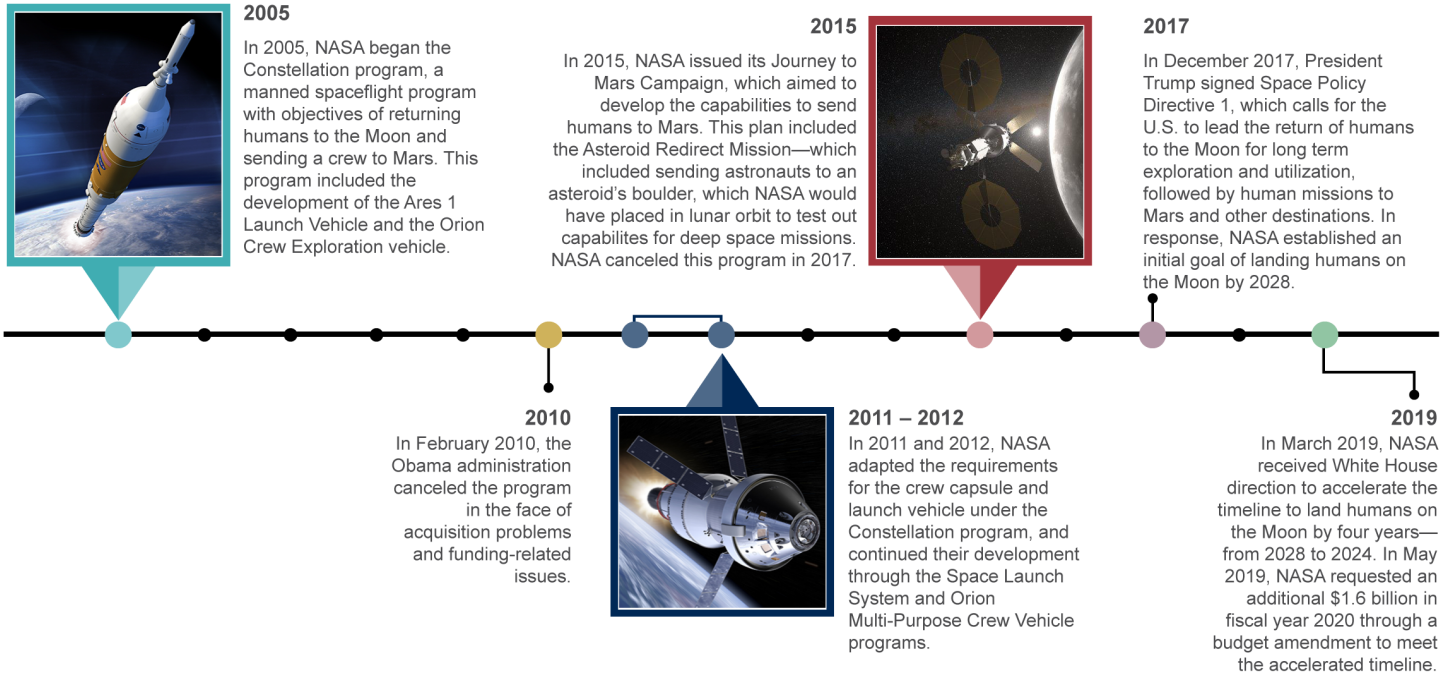
[7]GAO's best practices for the analysis of alternatives process are identified in *DOE and NNSA Project Management: Analysis of Alternative Could Be Improved by Incorporating Best Practices* (GAO-15-37). GAO applied these best practices in *Amphibious Combat Vehicle: Some Acquisition Activities Demonstrate Best Practices; Attainment of Amphibious Capability to be Determined* (GAO-16-22). We are in the process of refining these practices further and plan to include them in an upcoming revision of the GAO Cost Estimating and Assessment Guide.

Background

History of NASA Human Spaceflight Plans

NASA's human spaceflight plans have changed focus three times over the last 15 years. These plans have shifted back and forth between conducting a human lunar landing in order to inform the longer-term goal of human exploration of Mars and a mission that sends astronauts to an asteroid boulder in orbit around the Moon but does not include a lunar landing. Figure 1 highlights key events in NASA's human spaceflight plans from 2005 to 2019.

Figure 1: History of NASA Human Spaceflight Plans from 2005 to 2019



Source: GAO analysis of National Aeronautics and Space Administration (NASA) documents and prior GAO reports (data); Ares project office (top left image); NASA (top right image); NASA (bottom row image). | GAO-20-68

We have found that NASA has faced challenges developing systems capable of transporting humans to space over the past two decades.[8] These include development efforts under NASA's prior human spaceflight program—the Constellation program—which was canceled in the face of

[8]GAO, *NASA: Human Space Exploration Programs Face Challenges,* GAO-15-248T (Washington, D.C.: Dec. 10, 2014).

acquisition problems and funding-related issues. More recently, we have found that NASA has struggled to complete its current human spaceflight programs—Orion, SLS, and Exploration Ground Systems—within their established cost and schedule baselines.[9]

Establishing a sound business case to ensure resources align with requirements includes following best practices for product development and creating cost estimates and schedules. NASA's prior human spaceflight programs highlight challenges created when programs do not establish a sound business case. For example:

- In 2009, we found that NASA had not developed a solid business case—including firm requirements, mature technologies, a realistic cost estimate, and sufficient funding and time—needed to justify moving the Constellation program forward into the implementation phase.[10] We found that the program had not developed a solid business case because the program had a poorly phased funding plan that increased the risk of funding shortfalls, among other reasons. This resulted in the program not completing planned work to support schedules and milestones, and ultimately the program was canceled.
- Over the past 5 years, we have issued several reports assessing the progress of NASA's Orion, SLS, and Exploration Ground Systems programs relative to their agency baseline commitments and on technical challenges facing the programs.[11] In 2018, we found that all three programs have been at risk of cost and schedule growth since NASA approved their baselines, and have since experienced cost

[9]GAO-19-262SP and GAO-19-377.

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

[11]GAO, *Space Launch System: Resources Need to be Matched to Requirements to Decrease Risk and Support Long Term Affordability*, GAO-14-631 (Washington, D.C.: Jul. 23, 2014); *Space Launch System: Management Tools Should Better Track to Cost and Schedule Commitments to Adequately Monitor Increasing Risk,* GAO-15-596 (Washington, D.C.: Jul. 16, 2015); *NASA Human Space Exploration: Opportunity Nears to Reassess Launch Vehicle and Ground Systems Cost and Schedule,* GAO-16-612 (Washington, D.C.: Jul. 27, 2016); *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.: Jul. 27, 2016); *NASA Human Space Exploration: Delay Likely for First Exploration Mission,* GAO-17-414 (Washington, D.C.: Apr. 27, 2017); *NASA Human Space Exploration: Integration Approach Presents Challenges to Oversight and Independence,* GAO-18-28 (Washington, D.C.: Oct.19, 2017); and GAO-19-377.

growth and schedule delays.[12] This was in part because NASA did not follow best practices for establishing cost and schedule baselines for these programs, including not updating cost and schedule analyses to reflect new risks. As a result, NASA overpromised what it could deliver from a cost and schedule perspective. Further, in 2019 we found that NASA should enhance contract management and oversight to improve SLS and Orion program outcomes.[13] NASA's past approach in this area has left it ill-positioned to identify early warning signs of impending schedule delays and cost growth or reap the benefits of competition.

We have made 20 recommendations in prior reports to strengthen NASA's acquisition management of SLS, Orion, and Exploration Ground Systems. NASA generally agreed with GAO's recommendations, and has implemented eight of the recommendations. Further action is needed to fully implement the remaining recommendations. For example, in 2019, we recommended that NASA direct the SLS and Orion programs to reevaluate their strategies for incentivizing contractors and determine whether they could more effectively incentivize contractors to achieve the outcomes intended as part of ongoing and planned contract negotiations.[14] NASA agreed with the intent of this recommendation and stated that the SLS and Orion program offices will reevaluate their strategies for incentivizing contract performance as part of contracting activities including contract restructures, contract baseline adjustments, and new contract actions. We will continue to follow up on the actions the agency is taking to address this recommendation.

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 or may not include several projects. Projects are specific investments under a program that have defined requirements, life-cycle costs, schedules, and their own management structure. 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.

[12]GAO, *NASA: Assessments of Major Projects,* GAO-18-280SP (Washington, D.C.: May 1, 2018).

[13]GAO-19-377.

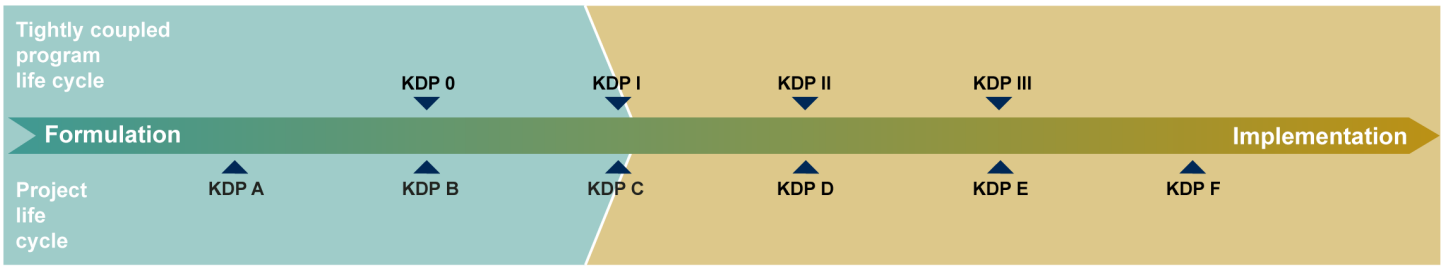
[14]GAO-19-377.

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. The life cycle for a single program closely resembles the life cycle for a spaceflight project. For example, the SLS program follows the project acquisition life cycle because it is not composed of multiple projects. Figure 2 depicts a notional NASA life cycle for a tightly coupled program and for a project.

Figure 2: NASA's 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-20-68

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 confirmation, 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.

To inform the management agreement and the agency baseline commitment, each program and project with a life-cycle cost estimated to be greater than $250 million must also develop a joint cost and schedule confidence level (JCL). A JCL produces a point-in-time estimate that includes, among other things, all cost and schedule elements from the start of formulation through launch, and incorporates and quantifies known risks, assesses the effects of cost and schedule to date on the estimate, and addresses available annual resources. The results of a JCL indicate the probability of a program or project's success of meeting cost and schedule targets.

Key Elements of NASA's Planned Return to the Moon

NASA has initiated multiple programs to help the agency achieve its Artemis III mission and longer-term lunar exploration goals. These programs include a platform in the lunar orbit, a landing system to put humans on the surface of the Moon, and robotic lunar landing services.

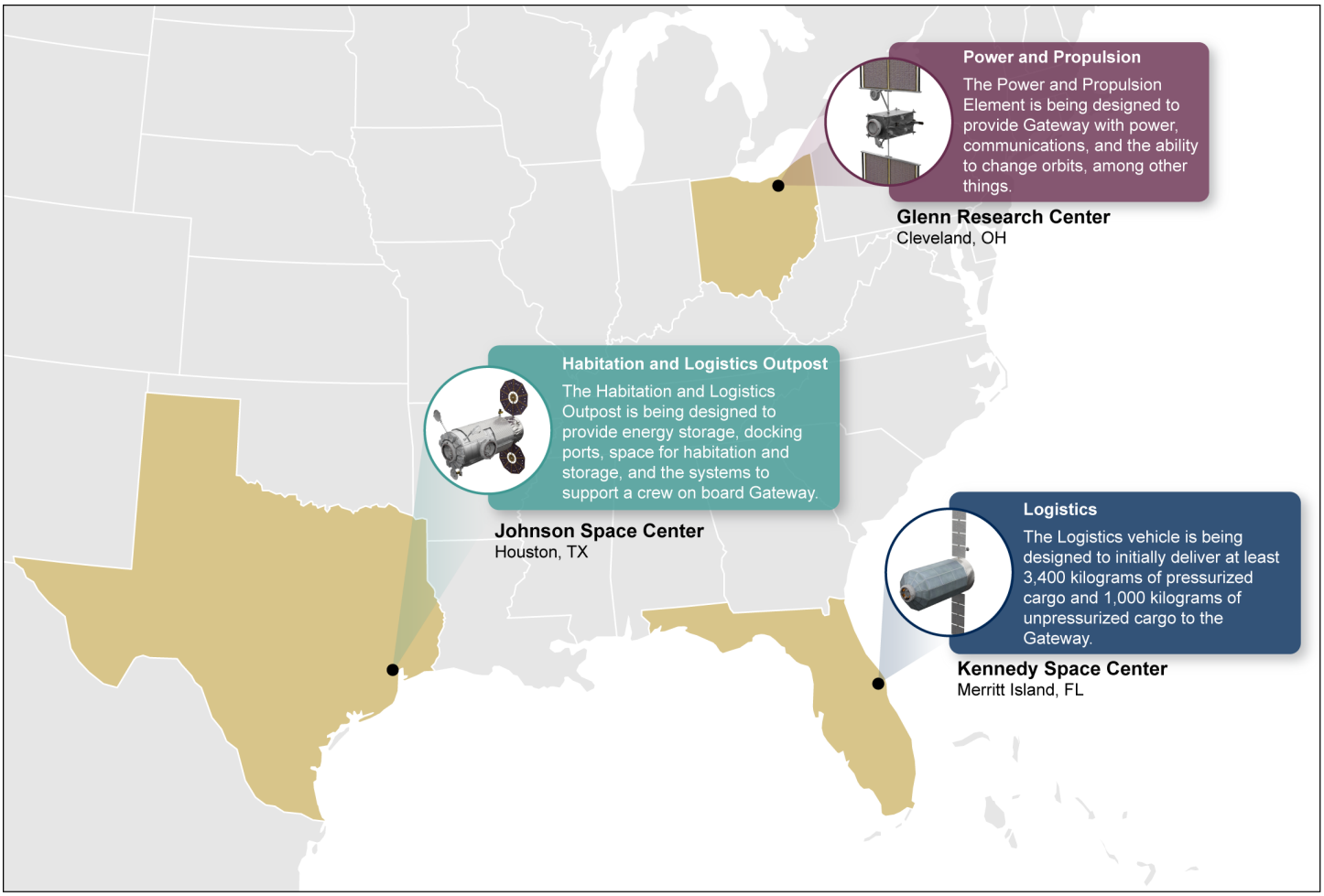
Gateway. The Gateway program aims to build a sustainable platform in lunar orbit to support human lunar exploration and scientific experiments by NASA and its commercial and international partners. NASA is planning for Gateway to maneuver to different orbits around the Moon, which will allow access to a variety of locations on the lunar surface.

The Gateway program is the first program NASA has designated as a tightly coupled program.[15] The program is composed of multiple projects, which are responsible for executing portions of the Gateway mission.[16] Individual teams manage the projects and each project will have its own cost estimate and launch readiness date. Gateway program management is responsible for ensuring the overall integration of all the individual projects. See figure 3 for a description of the three Gateway projects that NASA has initiated.

[15]The Constellation program incorporated elements of the tightly coupled program approach, but no formal NASA program management designation was defined in policy or guidance at that time.

[16]NASA calls the individual projects within the Gateway program modules. For the purpose of this report, we will refer to the modules as projects.

Figure 3: Gateway Program Project Descriptions



Source: GAO analysis of National Aeronautics and Space Administration (NASA) documents (text); NASA (images); MapResources (map). | GAO-20-68

In addition to Gateway, NASA initiated several other programs:

Human Landing System. The Human Landing System, or lunar landers, is to provide crew transportation from Gateway to the lunar surface and back and demonstrate capabilities required for deep space missions.[17] NASA anticipates that there will be three stages to the landers—a

[17]For the initial 2024 mission, Human Landing System providers may opt to connect directly with the Orion capsule in space and not connect with Gateway.

descent, ascent, and transfer stage—but the number of stages may vary depending on the contractors that NASA selects to develop the system. NASA is planning for the descent stage to serve as a crew and cargo lander; the ascent stage to bring crew back to Gateway from the lunar surface; and the transfer stage to transfer the ascent and descent stages from Gateway orbit to a lower lunar orbit for the landing.[18]

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. 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.

Commercial Lunar Payload Services. Under Commercial Lunar Payload Services, commercial partners provide 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 humans to return to the lunar surface.

Volatiles Investigating Polar Exploration Rover. NASA plans to develop a robotic lunar rover for long duration operations to investigate volatiles—which include water, carbon dioxide, and other chemicals that boil at low temperatures—at the lunar South Pole that could be used to support sustained human presence on the Lunar surface. NASA plans to utilize landers from the Commercial Lunar Payload Services to deliver the rover to the lunar surface.

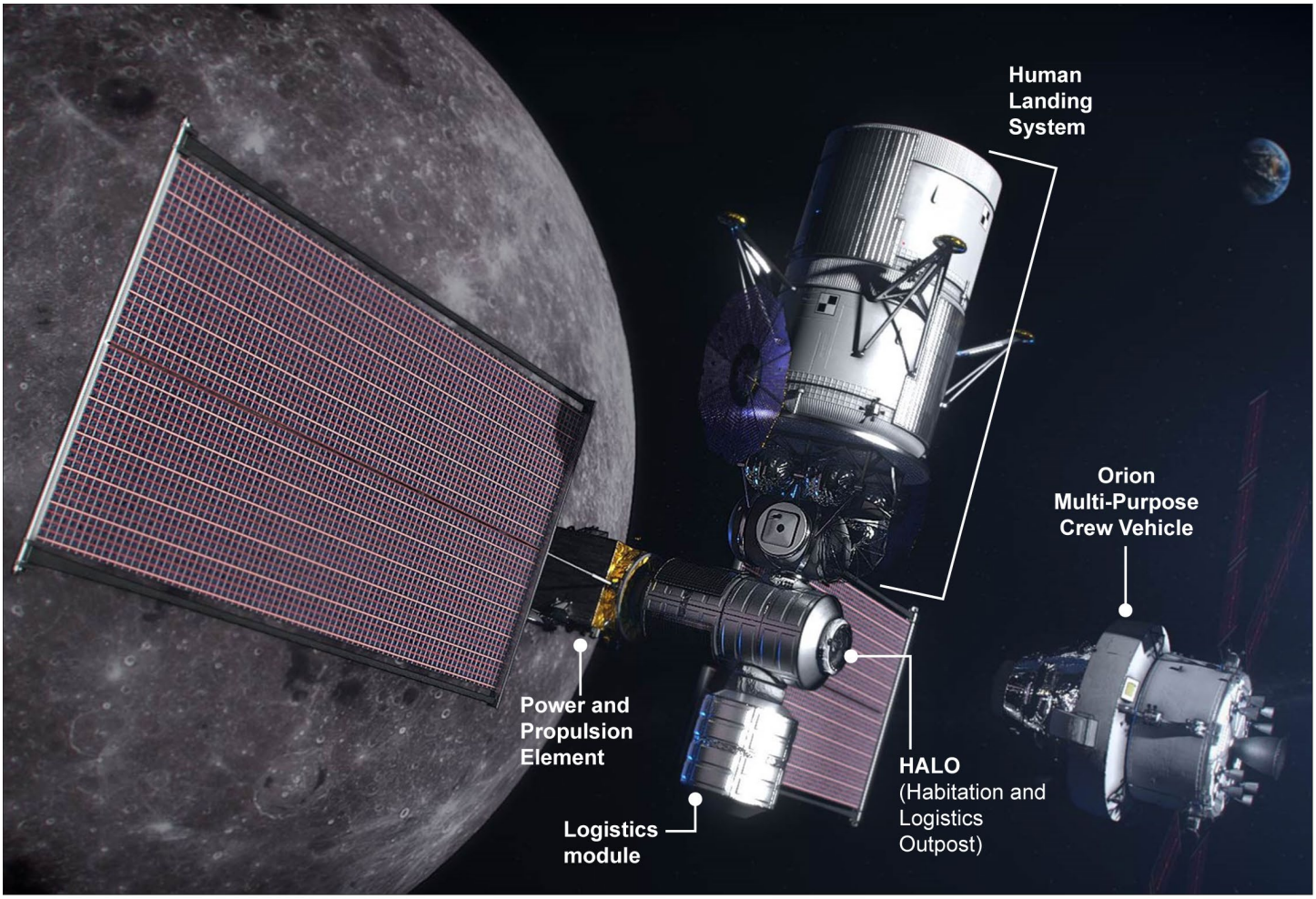
Orion and SLS. Orion is the crew capsule to transport humans from the Earth to Gateway and beyond. SLS is the vehicle NASA will use to launch the Orion crew capsule and cargo beyond low-Earth orbit, including to Gateway.

Figure 4 shows a notional configuration of Gateway, the first integrated Human Landing System, and the Orion crew capsule. In this configuration, the Human Landing System ascent stage, Gateway

[18]Gateway will be orbiting the Moon in a near rectilinear halo orbit, which enables global lunar access and promotes access to the lunar poles.

Logistics and Power and Propulsion Element (PPE), and Orion crew capsule are designed to dock with the Gateway Habitation and Logistics Outpost.

Figure 4: Notional Configuration of Gateway, Human Landing System, and Orion Multi-Purpose Crew Vehicle for Artemis III Mission



Source: National Aeronautics and Space Administration (NASA). | GAO-20-68

The Advanced Exploration Systems organization is responsible for overseeing the Gateway and Human Landing System programs and reports to NASA's Associate Administrator for Human Exploration and Operations Mission Directorate (HEOMD). Another organization within HEOMD—Exploration Systems Development—is responsible for the

development of the Orion crew capsule. The Office of the Chief Engineer and Office of the Chief Financial Officer are responsible for NASA policies and guidance related to the development of these systems.

NASA Adjusted Its Acquisition Plans to Support 2024 Lunar Landing

After the March 2019 announcement to accelerate the human lunar landing to 2024, NASA acknowledged that it could not complete all of its original plans under the new time frame. The original plans for a human lunar landing in 2028 included an expanded Gateway and uncrewed demonstrations of components of the Human Landing System. In response to the new direction, NASA decided to execute its lunar plans in two phases. Phase 1 focuses on systems NASA identified to support the Artemis III mission in 2024. Phase 2 builds upon Phase 1 efforts and focuses on establishing a long-term presence on the lunar surface through future Artemis missions, and is not currently the focus of NASA's efforts (see figure 5).

Figure 5: NASA Phase 1 and Phase 2 Lunar Plans

Phase 1: Today through 2024 human lunar landing with an emphasis on speed	Phase 2: Efforts after 2024 lunar landing with an emphasis on sustainability
The first three projects of **Gateway**—Power and Propulsion Element, a Habitation and Logistics Outpost, and a Logistics vehicle—will launch and be assembled in space.	Additional projects of **Gateway**, potentially including a U.S. habitat, additional logistics deliveries, and international partner projects—will launch and be assembled in space.
A **Human Landing System** to enable short-term exploration of the lunar surface by at least two astronauts at the lunar South Pole.	Human landing services to enable longer-term exploration of the lunar surface by up to four astronauts.
Initial surface space suits with reduced mass and streamlined capabilities.	An enhanced space suit including extended service life.
Landings of **Commercial Lunar Payload Services** landers and the delivery of a lunar rover.	Additional landings of **Commercial Lunar Payload Services** landers and rovers.
Three flights of the **Orion** crew capsule will launch on the **Space Launch System** (uncrewed and crewed flight tests and delivery of astronauts to **Gateway**).	Additional **Orion** and **Space Launch System** flights to **Gateway**.

Source: GAO analysis of National Aeronautics and Space Administration (NASA) documents. | GAO-20-68

NASA made several changes to its prior lunar plans to increase the speed of developing the systems needed to meet the aggressive timeline for the Artemis III mission. For example:

- NASA reduced the scope of the Gateway program for Phase 1 by deferring or eliminating components, and changing its configuration. NASA removed a component that an international partner had planned to contribute and deferred work on a habitation component and other potential international contributions to Phase 2. Acknowledging that some elements of Gateway had to be deferred or eliminated for the first phase is a positive step NASA has taken to try to achieve an aggressive schedule.
- In some cases, NASA changed the acquisition strategy to increase the speed of development work. For example, NASA had planned to build the Habitation and Logistics Outpost in-house, but due to the 2024 acceleration announcement, now plans to award a contract for its development. In addition, NASA changed its plans to acquire the Human Landing System as an integrated system instead of by stage to meet the accelerated timeline.
- NASA developed a broad agency announcement for the Human Landing System with the goal of awarding contracts by the end of January 2020.[19] NASA released a draft broad agency announcement for the integrated system in July 2019, about 4 months after receiving direction to land humans on the Moon by 2024. Human Landing System program officials raised concerns about the program's ability to meet the 2024 timeline, but said they are trying to mitigate this risk by incorporating input from prior studies and feedback from industry into the program's draft broad agency announcement.

See table 1 for the status of NASA's lunar programs, including changes NASA made to prior plans and timelines to meet the 2024 lunar landing goal.

[19]A broad agency announcement is a general announcement of an agency's research interest including criteria for selecting proposals and soliciting the participation of all offerors capable of satisfying the government's needs.

Table 1: Status of the NASA Lunar Programs to Support Artemis III Mission in 2024 as of October 2019

Program/project	Acquisition status	Schedule and cost estimates, if available	Changes made to meet the accelerated Artemis III timeline
Gateway Power and Propulsion Element	In May 2019, NASA awarded a contract to Maxar Technologies Inc. to develop and demonstrate power, propulsion, and communications capabilities. Maxar will own the element through launch and conduct an on-orbit demonstration of up to 1 year. After successful demonstration, NASA will have the option to acquire the element.	Maxar plans to launch the element in 2022. The contract that was awarded had a total value of $375 million.	None.
Gateway Habitation and Logistics Outpost	In July 2019, NASA issued a Justification for Other than Full and Open Competition to support its plans to award a follow-on contract solely to Northrop Grumman Innovation Systems for development of the Habitation and Logistics Outpost. This sole source contract, if awarded, would be a follow-on to the originally competitively awarded NextSTEP-2 initiative to develop habitation prototypes.[a] NASA plans to award the contract by the end of 2019.	NASA plans to launch the outpost in late 2023. NASA has not released a potential maximum contract award value.	NASA was planning to lead the development of the Gateway Habitation and Logistics Outpost, but the program has now selected a single contractor to deliver the minimum habitation capability. NASA also plans to add additional capabilities to the outpost, in part because NASA and the European Space Agency agreed to defer European Space Agency contributions. The additional capabilities NASA is adding include docking to the Power and Propulsion Element, and adding a communications capability and plumbing to allow for refueling.
Gateway Logistics Services	In August 2019, NASA released a request for proposals for Gateway Logistics Services, which includes the first logistics vehicle to support the Artemis III mission. NASA plans to make a selection decision and award one or more contracts in December 2019.	NASA plans to launch the first logistics vehicle in 2024. NASA plans to award a firm fixed-price contract for logistics services with a maximum value of up to $7 billion over 15 years.	None.
Human Landing System	According to NASA, in May 2019, the agency selected 11 companies to conduct studies and produce prototypes of human landers for the descent, transfer, and refueling elements. NASA will use these studies to inform the integrated lander proposals. NASA plans to award one or more contracts in January 2020.	NASA plans to launch the integrated human landing system in 2024. NASA has not released a potential maximum contract award value.	NASA had planned to procure its human lunar landers by individual stages of the system, but now plans to procure them as an integrated system. In addition, NASA has eliminated uncrewed demonstrations. Program officials said each contractor will undergo ground testing and each stage will have operational time without crew while traveling to Gateway. NASA requested an additional $1 billion for the Human Landing System program in its fiscal year 2020 budget amendment.

Program/project	Acquisition status	Schedule and cost estimates, if available	Changes made to meet the accelerated Artemis III timeline
Commercial Lunar Payload Services	In November 2018, NASA awarded multiple-award, indefinite delivery/indefinite quantity contracts to 9 companies to deliver science and technology payloads to the lunar surface.[b] In May 2019, NASA selected three commercial Moon landing service providers for the initial delivery of payloads. However, in July 2019, one of the selectees informed NASA that it would not be able to carry out the task order and NASA terminated the task order. In July 2019, NASA released a request for proposal for additional vendors to support the next generation of lunar landers that can land larger payloads on the surface of the Moon.	The two remaining companies that NASA selected for initial delivery of payloads currently plan to land on the lunar surface in July 2021. The maximum combined contract value for all 9 indefinite delivery/indefinite quantity contracts is $2.6 billion over the next 10 years.	NASA plans to accelerate award of indefinite delivery/indefinite quantity contracts to additional vendors that can provide enhanced capabilities to deliver larger payloads, which may include tools, instruments, or other supplies for the Artemis III mission. NASA requested an additional $90 million to support the purchase of commercial services to deliver a rover to the Moon in its fiscal year 2020 budget amendment.
Space Suits	NASA plans to develop lunar surface space suits in-house, with NASA serving as the prime integrator of industry-supplied components.	NASA plans to use two of these suits for the Artemis III mission in 2024. NASA has not yet created a preliminary cost estimate for the suits.	According to NASA officials, the agency has been developing an enhanced Extravehicular Activity capability suit, and plans to modify this spacesuit to reduce mass and streamline capabilities. NASA plans to enhance suit design for future missions, with additional capabilities such as extended service life.
Volatiles Investigating Polar Exploration Rover	NASA plans to build this rover in-house and use Commercial Lunar Payload Services to deliver the rover to the surface of the Moon.	NASA plans to launch the rover in late 2022. Science Mission Directorate officials stated the project is targeting a cost of about $250 million.	None.
Space Launch System (SLS) and Orion Multipurpose Crew Vehicle (Orion)	Orion and Space Launch System are in development and have integration and testing activities remaining before the first integrated flight.	After a series of delays, NASA had planned to conduct the uncrewed demonstration mission of SLS and Orion in June 2020, but the agency is re-evaluating this date. In 2018, NASA estimated the life-cycle cost of the Orion program at $11.7 billion and the SLS program at $10.7 billion. The agency is re-evaluating the cost of the SLS program.	NASA requested an additional $651 million in its fiscal year 2020 budget amendment to ensure the SLS and Orion programs maintain their schedules for uncrewed and crewed demonstration missions. NASA will need to conduct these missions prior to 2024 in order to support the accelerated timeline. Of the $651 million requested, NASA requested $510.5 million for the SLS program and $140.5 million for the Orion program.

Source: GAO analysis of NASA documents. | GAO-20-68

[a]NASA's Next Space Technologies for Exploration Partnerships (NextSTEP) is a public-private partnership model that seeks commercial development of deep space exploration capabilities.

[b]An indefinite delivery/indefinite quantity (IDIQ) 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). When two or more contracts are awarded under a single solicitation for the same or similar supplies or services, these contracts are known as multiple award IDIQ contracts. Agencies establish a group of prequalified contractors to compete for future orders.

NASA is still considering the extent to which competition will be part of its acquisition plans to meet the accelerated 2024 landing. Competition may be a critical tool for achieving the best possible return on investment for taxpayers, and can help improve contractor performance.[20] In addition, in 2014, we found there were competition opportunities for future SLS development work that may promote long-term affordability.[21] We recommended that NASA assess the extent to which the agency could competitively procure development and production of future elements of the SLS to promote affordability. NASA agreed with this recommendation. However, NASA's progress implementing it has been limited. For example, NASA awarded a sole-source contract for the upper stage engine, which further limits an opportunity for competition for the program.

For Gateway Logistics Services and the Human Landing System, NASA officials stated that they are considering awarding multiple initial contracts. If NASA does award multiple contracts, NASA officials stated they would then be able to have the contractors compete for further development of the components and possibly for specific missions. Conversely, NASA does not plan to competitively award a contract for the Gateway Habitation and Logistics Outpost, citing the aggressive Artemis III schedule as a factor for this decision.

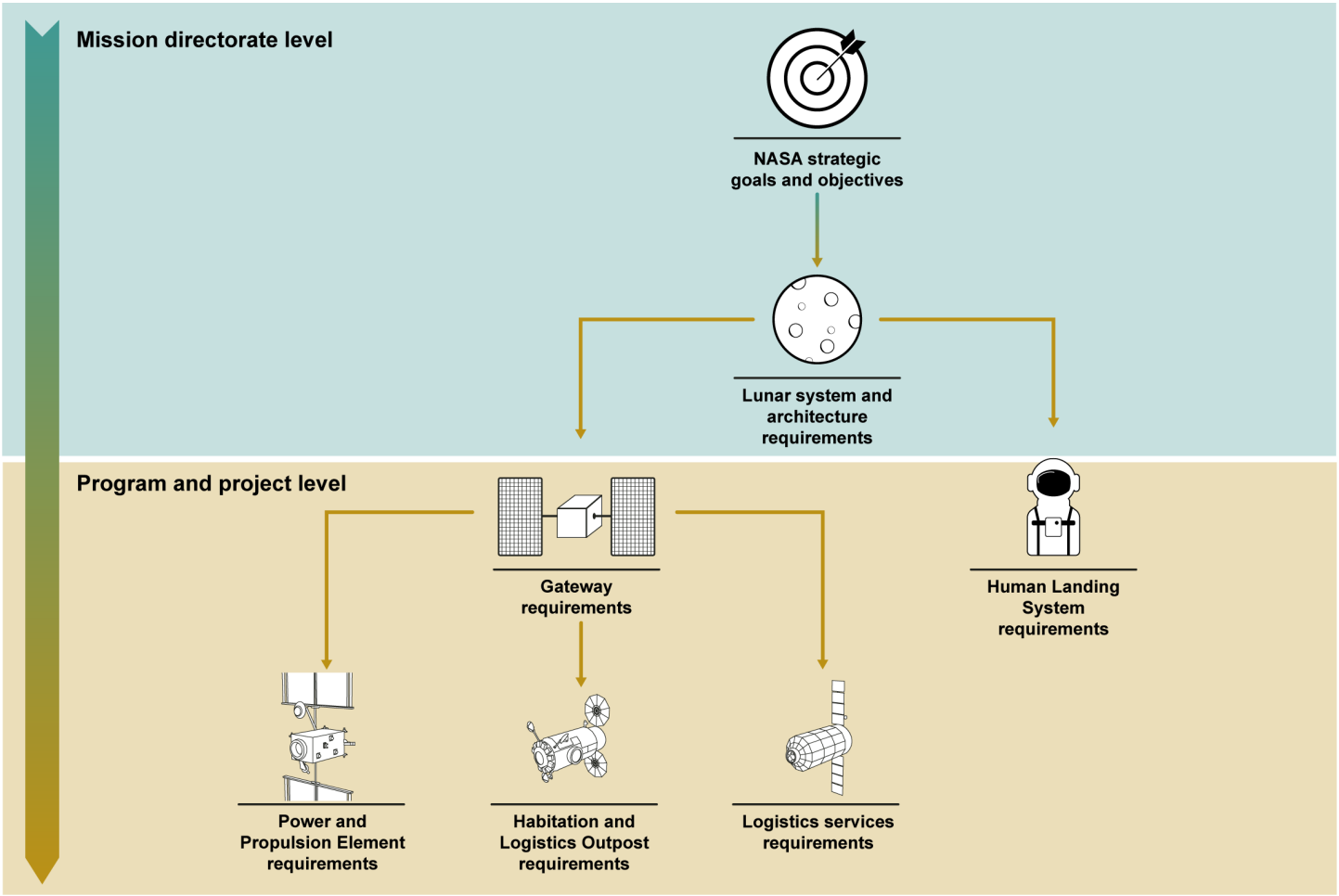
[20]Paul Dennett, Office of Federal Procurement Policy Administrator, Memorandum for Chief Acquisition Officers Senior Procurement Executives, Enhancing Competition in Federal Acquisition (May 31, 2007) and GAO, *Federal Contracting: Opportunities Exist to Increase Competition and Assess Reasons When Only One Offer Is Received,* GAO-10-833 (Washington, D.C.: July 26, 2010).

[21]GAO, *Space Launch System: Resources Need to Be Matched to Requirements to Decrease Risk and Support Long Term Affordability,* GAO-14-631 (Washington, D.C.: July 23, 2014).

NASA Risks Integration Challenges Because Lunar Mission Requirements Have Not Yet Been Established

NASA has identified the components of its lunar architecture—such as Gateway and lunar landers—but it has not fully defined a system architecture or established requirements for its lunar mission. A system architecture, among other things, defines the dependencies and interfaces between the components. The NASA systems engineering handbook states that defining the system architecture early enables NASA to develop components separately from each other while ensuring that they work together effectively to achieve top-level requirements. For example, a system architecture for the Artemis III mission would describe the relationships and interfaces between Gateway and the Human Landing System, ensuring that after the two programs are completed, they will work together properly to execute the mission. Figure 6 is an illustration of how specific program and project requirements flow down from NASA's strategic goals and objectives.

Figure 6: Notional Flow-Down of NASA Strategic Goals and Objectives to Program and Project Requirements



Source: GAO analysis of National Aeronautics and Space Administration (NASA) guidance and documents (text); NASA (images - bottom row). | GAO-20-68

NASA officials told us they started with defining individual program and project requirements, and then plan to define the system architecture in an architecture definition document and the lunar system requirements in six separate HEOMD documents.[22] These documents are in various stages of completion. HEOMD officials said they expect to finalize the overall architecture definition document at the end of 2019. They plan for this document to include a description of the integrated architecture, including the architecture's components and high-level interfaces required for initial human lunar surface missions. In addition, HEOMD has six other documents that establish requirements for human space exploration missions, among other things. Three of these documents are currently outdated because they do not address lunar landings.[23] HEOMD officials stated that they do not expect the documents to be updated before the end of 2019.

NASA officials told us that they did not start with these higher-level architecture and all of the requirements documents because they thought it was important to first establish requirements for individual programs and review what contractors proposed for Gateway and the Human Landing System, and incorporate industry input on what requirements are feasible. The Human Landing System draft request for proposals contained a notional architecture that has three stages, but the agency is open to selecting contractors that do not follow this notional architecture.

In our work to develop a framework for assessing and improving enterprise architecture management, we found that a mature architecture should ensure that components of the architecture align their plans with

[22]NASA has developed drafts of four of the six documents. NASA, HEOMD-001 *Human Exploration and Operations Exploration Objectives, Revision A* (Jul. 31, 2017); HEOMD-002 *Human Exploration and Operations Mission Directorate Configuration Management Process, Initial Release* (May 22, 2017); HEOMD-003 *Crewed Deep Space Systems Certification Requirements and Standards for NASA Missions, Draft* (May 24, 2019); and HEOMD-004 *Human Exploration Requirements* (Feb. 5, 2018). Human Exploration and Operations Mission Directorate officials said they plan to describe the architecture's concept of operations in the fifth document and how NASA plans to utilize the programs in operations in the sixth document.

[23]One document, HEOMD-003, was updated in May 2019, and although it is in draft form, was incorporated into lunar program requirements. NASA stated that they are not planning on proceeding with the development of HEOMD-005 and HEOMD-006 at this time.

enterprise-level plans.[24] Establishing such alignment is essential to achieving goals and supporting solutions that are appropriately integrated and compatible.

NASA's approach of defining the lunar architecture and associated requirements concurrently with programs setting their own requirements presents the risk of mismatches of requirements across and within programs. Such mismatches increase the risk of technical problems, schedule delays, and cost overruns. For example, the Gateway program is tracking the potential misalignment of requirements as a risk because the PPE project finalized its requirements before the Gateway program finalized corresponding requirements at the program level.[25] PPE officials stated they finalized their requirements first because they had started work under a prior project and, as a result, moved quickly through early development activities.

The Gateway program and PPE project officials said that when they reviewed the PPE requirements with Gateway's requirements, they found two possible gaps. For example, NASA officials explained that there is a difference in the amount of power the PPE contractor is required to deliver for the PPE and Gateway's requirements for power. The program is working with the PPE project office and contractor to study the potential gaps and determine how to resolve them if needed. The Gateway program officials said they would continue to assess gaps and risks related to requirements alignment for all projects.

HEOMD officials agreed that there is a risk of discovering integration challenges across programs. NASA officials have taken action on one strategy to minimize this risk, and are considering two other potential mitigation strategies. To help ensure that the components of the lunar architecture can work together, NASA included international interoperability standards in its requests for proposals for the lunar

[24]Enterprise architecture provides a clear and comprehensive picture of the structure and substance of any purposeful activity, including a functional or mission area that cuts across organizational boundaries. It also is an essential tool for effectively and efficiently engineering business or mission processes and for implementing and evolving supporting systems. GAO, *Organizational Transformation: A Framework for Assessing and Improving Enterprise Architecture Management (Version 2.0),* GAO-10-846G (Washington D.C.: August 2010).

[25]For the Gateway program, requirements are set both at the program level, to align with mission and agency needs and objectives, as well as at the project level, to specify needs and capabilities for the project.

programs. For example, there are standards for how the components will dock with each other. NASA officials said that including these standards would help mitigate integration challenges.

The two other potential mitigation strategies are the following:

- **Establish a Lunar Exploration Control Board.** NASA is in the process of establishing a board that would act as an architecture configuration management body. Configuration management is a process used to control changes to top-level requirements. In our prior work on developing and maintaining systems or networks, we found that effective configuration management is a key means for ensuring that additions, deletions, or other changes to a system do not compromise the system's ability to perform as intended.[26] The board could serve as a body to make decisions that affect multiple lunar programs and ensure that changes to components of the lunar architecture do not affect NASA's ability to accomplish a successful lunar landing.
- **Hold cross-program synchronization or integration reviews.** To help ensure that requirements are aligned across programs, a senior HEOMD official said NASA plans to hold cross-program synchronization or integration reviews. However, the official said NASA has not defined at what level those reviews would occur, when those reviews would occur, or what specific contractor data would be reviewed. Ensuring the Lunar Exploration Control Board is involved in these reviews will help the board in its role as a configuration management body and inform decisions that affect multiple lunar programs.

NASA's system engineering handbook states that activities to integrate systems throughout a system life cycle help to make sure that integrated system functions properly. These activities include conducting analysis to define and understand integration between systems. NASA is moving quickly to develop individual programs and projects that must work together as part of the broader lunar architecture. Delaying decisions about how and when NASA plans to hold synchronization or integration reviews risks discovery of changes late in the acquisition process. As stated in NASA's system engineering guidance, the later in the development process changes occur, the more expensive they become.

[26]GAO, *National Guard: Effective Management Processes Needed for Wide-Area Network,* GAO-02-959 (Washington, D.C.: Sept. 24, 2002).

NASA's Initial Decisions for Cost and Schedule Estimating Include Benefits, but Limit Some Information for Decision Makers

NASA has taken positive steps to increase the visibility into the cost and schedule performance of the Gateway program's projects, but decisions on analyses to support program-level cost and schedule are still pending. In addition, the NASA Administrator has stated that Artemis III may cost between $20 billion to $30 billion, but NASA officials stated that the agency does not plan to establish an official cost estimate.

Gateway Structure Provides Increased Visibility for Project Cost and Schedule Performance, but Decisions on Program Reviews and Analysis Are Pending

Gateway Costs

As of October 2019, NASA was still defining its approach for developing cost and schedule estimates for all programs and projects in the lunar architecture, but we found NASA has made some decisions related to the structure of the Gateway program that will provide visibility into cost and schedule performance. In particular, NASA's decision to structure the Gateway program as a tightly coupled program means that the projects that compose the Gateway—Power and Propulsion, Habitation and Logistics Outpost, and Logistics—are to develop individual project cost and schedule baselines by which performance will be measured. NASA officials stated that they expect this will provide accountability for each project to adhere to its cost and schedule baseline. This structure is a positive step for NASA to improve management of large, complex programs, and could have been beneficial to previous human spaceflight programs. For example, cost and schedule baselines for key hardware elements of the Space Launch System program—such as the core stage—might have provided earlier warning signs of development challenges affecting cost and schedule performance.

NASA policy requires tightly coupled programs with a life cycle cost estimate greater than $250 million to conduct a program-level joint cost and schedule confidence level (JCL) to inform an agency baseline

commitment. A JCL is a calculation that NASA uses to estimate the probability of success of a program or project meeting its cost and schedule baselines.[27]

However, NASA decided to remove the requirement for the Gateway program to establish an agency baseline commitment, and instead, require the program to document its cost and schedule estimates for phase 1 in a program commitment agreement. NASA officials explained that the agency viewed requiring the Gateway program to conduct a JCL to inform cost and schedule baselines as duplicative of analysis the projects are required to conduct to inform their project level baselines. In October 2019, Gateway program officials stated they have reconsidered this direction and now plan to conduct a program-level JCL. However, given that NASA officials previously determined they would not require the Gateway program to establish a baseline that is informed by a program-level JCL, the decision to conduct a JCL is subject to change again.

NASA's commitment to the program's October 2019 decision to conduct a program-level JCL would enhance oversight and management for Gateway. NASA's cost estimating handbook states that a JCL can serve as a valuable management tool that helps enforce some best practices of program planning and control, and potentially enhance vital communication to various stakeholders. Having a program-level JCL could help the program identify additional cost and schedule risks associated with integration of, or dependencies across, Gateway components that individual projects may not identify. As a tightly coupled program, Gateway has project schedules that are dependent on one another. For example, PPE provides power to subsequent Gateway components, such as the Habitation and Logistics Outpost, and must be launched and in lunar orbit for the outpost to dock with PPE. A program-level JCL would be able to quantify risk of delay across all dependent activities, regardless of which individual project experiences the delay. It would also provide NASA decision-makers and external stakeholders, such as Congress, with the probability of the program meeting both its cost and schedule commitments to support the Artemis III mission.

Gateway Schedule

The Gateway program is also the program in the lunar architecture that is the furthest along in developing a schedule aside from the SLS, Orion,

[27]NASA policy also allows programs to tailor requirements.

and Exploration Ground Systems programs. The program expects to have an integrated master schedule in late 2019, but in the meantime has developed a high-level notional schedule.[28] We identified two challenges with the Gateway program's schedule that stem from decisions to meet the program's rapid pace of development.

Program and project technical reviews do not align. The NASA program management handbook states that lower-level technical reviews, such as project preliminary design reviews, are typically conducted prior to the program-level reviews.[29] In addition, GAO's Schedule Assessment Guide states that lower-level project schedules should be consistent with upper-level program review milestones.[30] This creates consistency between program and project schedules, which enables different teams to work to the same schedule expectations and ensures the proper sequencing of activities.

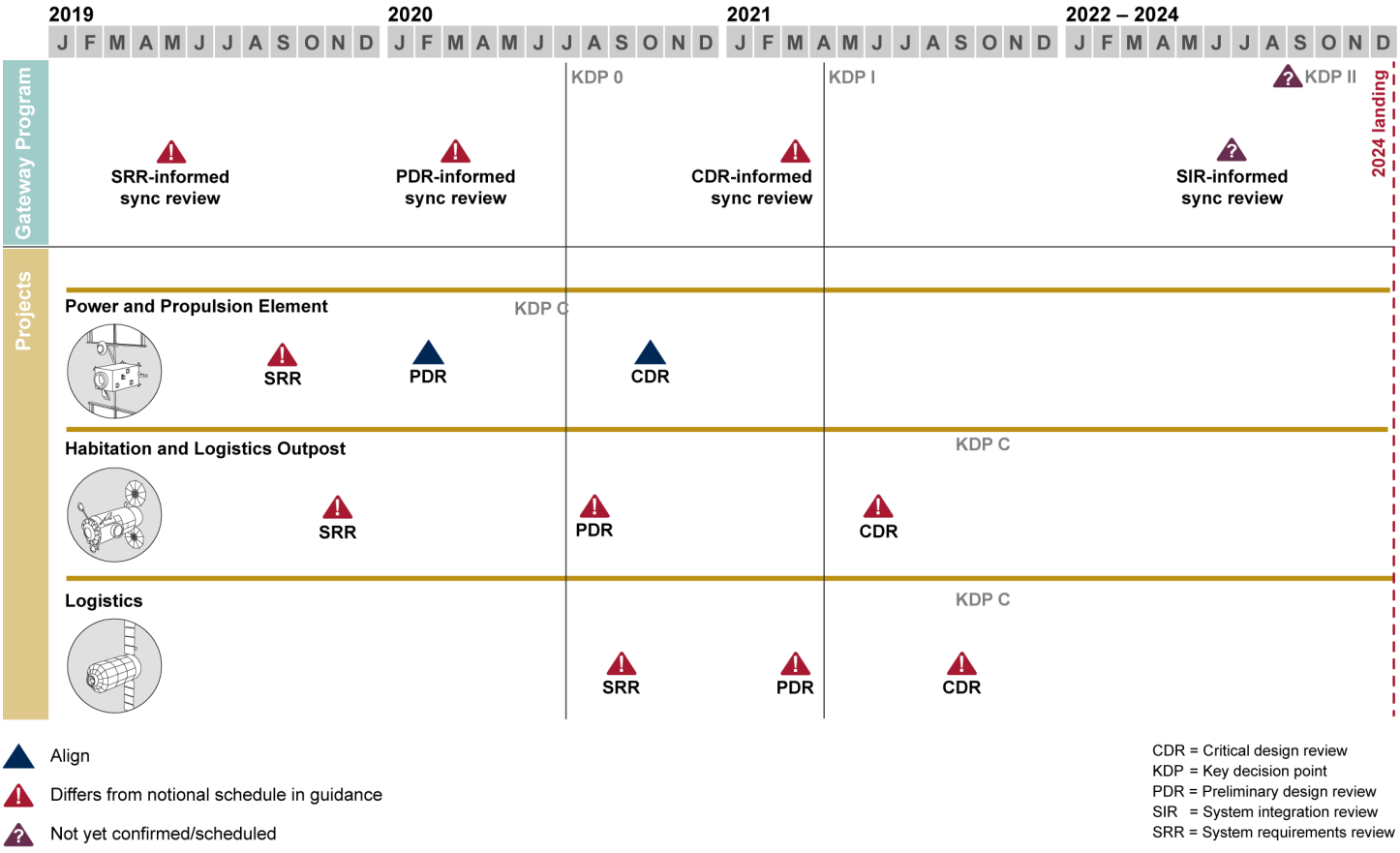
The Gateway program obtained approval from the NASA Associate Administrator to tailor its review schedule. This includes the replacement of traditional reviews with program sync reviews informed by project-level technical reviews. The program has some of the project-level technical reviews for its projects—PPE, Habitation and Logistics Outpost, and Logistics—occurring after equivalent Gateway program-level reviews. The Gateway program-level reviews are referred to as sync reviews, during which information is assessed across all projects. For example, the Logistics project plans to hold its preliminary design review after the Gateway program preliminary design-informed sync review. Figure 7 shows the preliminary Gateway program schedule and identifies reviews that differ from the notional tightly coupled program schedule found in NASA guidance.

[28]An integrated master schedule is a schedule that includes the entire required scope of an effort, including the effort necessary from all government, contractor, and other key parties for a program's successful execution from start to finish.

[29]Programs and projects hold a preliminary design review to demonstrate that the preliminary design meets all system requirements with acceptable risk and within cost and schedule constraints.

[30]GAO-16-89G.

Figure 7: Preliminary Gateway Program and Project Schedule Compared to Notional Tightly Coupled Schedule Identified in NASA Guidance



Source: GAO analysis of National Aeronautics and Space Administration (NASA) guidance and documents (text); NASA (image). | GAO-20-68

Without the results of project-level reviews, program officials may have limited information to assess progress at program-level reviews. This opens up the possibility of costly re-designs at later stages of the program life cycle. Gateway program officials said as the program progresses, they plan to assess the risk of holding a project-level review after a program-level review against the risk of delaying a program-level review to hold all the project-level reviews first. Officials added that they are still reviewing their approach for the timing of the reviews. We will continue to follow up through future work on the Gateway program's risk assessments related to the timing of the technical reviews.

Scheduling of key program milestone reviews after 2021 deferred. The Gateway Program does not yet have key milestone reviews—known as key decision points (KDP)—scheduled after 2021 (see figure 7). Currently, the final key decision point scheduled for the program is KDP I in 2021, which evaluates the completeness of the preliminary design, including for projects, and determines the program's readiness to begin the detailed design phase. However, NASA policy requires the program to conduct two other key decision points that the Gateway program has not yet scheduled. Program officials told us that they want to determine the need for subsequent decision points after the systems have matured further in their development.

During the period between 2021 and 2024, the Gateway program plans to launch and assemble its three components—PPE, Habitation and Logistics Outpost, and the first logistics vehicle—and integrate with the Human Landing System and Orion. It may be appropriate not to schedule a KDP III—a decision point that evaluates the readiness of the program, including its projects, for launch and early operations—for the Gateway program since the projects will launch separately and conduct operations on different timelines. However, not having a KDP II—a decision point that evaluates the program's readiness for assembly, integration, and testing, prior to a system integration review—will limit information available to senior leaders for decision-making. Without scheduling a KDP II, NASA risks not having a formal mechanism to ensure that NASA has identified and sufficiently addressed any integration issues across the three projects.

NASA Does Not Plan to Develop a Lunar Mission Cost Estimate

The NASA Administrator made a public statement that the Artemis III mission may cost between $20 billion and $30 billion, but NASA officials told us they do not plan to develop an official cost estimate for the Artemis III mission. A senior HEOMD official said that the agency developed a cost estimate that included costs for the lunar mission to 2028 to support budget submissions. However, the official said this life-cycle cost estimate included costs outside of the Artemis III mission, such as for missions later than Artemis III, and may not include integration and overall management costs. NASA officials told us that it is complicated to separate out costs for each mission and, as a result, do not plan to develop an Artemis III cost estimate. In addition, senior NASA officials stated that many of the programs needed to execute the mission are currently in the early stages of acquisition, and therefore NASA has limited cost information. Meanwhile, NASA requested an additional $1.6

billion in fiscal year 2020 above its initial budget request to support the Artemis III mission.

Cost estimates provide management with critical cost-risk information to improve the control of resources in the present and future. GAO's Cost Estimating and Assessment Guide states that a life-cycle cost estimate enhances decision-making, especially in early planning of an acquisition.[31] Individual program cost estimates would not capture the integration costs across programs. Without an Artemis III cost estimate, NASA will not be able to effectively monitor total mission costs and Congress would have limited insight into mission or program affordability when making decisions about each year's budget request.

NASA Conducted Studies to Inform Lunar Plans, but Did Not Fully Assess Alternatives

Given the breadth of activity and funding required for NASA to achieve a human lunar landing, a number of stakeholders have advocated for NASA to carry out this mission in a different way than NASA is pursuing. For example, one advocate proposed alternative lunar architectures that do not include the use of Orion, SLS, or Gateway, and instead rely on the use of commercial vehicles, and a former NASA associate administrator has promoted increased use of NASA's current programs, including SLS.

Agencies can use the process of assessing alternatives to justify their decisions and demonstrate careful planning. While NASA policy does not require programs to analyze alternatives before starting work, GAO best practices state that analyzing alternatives provides a framework to help ensure that entities consistently and reliably select the alternative that best meets the mission need based on selection criteria, such as safety, cost, or schedule. Similarly, the Department of Defense, an agency that also invests billions of dollars in acquisitions, considers an analysis of alternatives a key input to defining a system's capabilities and assessing affordability. We previously found that analyzing alternatives is a key element in establishing a sound business case for a new architecture or program. Having a strong business case, including a formal assessment of alternatives, would help NASA effectively communicate its decisions to various stakeholders and facilitate a better understanding of its current lunar plans.

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

NASA officials told us that they arrived at the current architecture and the designs of its lunar programs by conducting numerous studies and analyses over multiple decades. These studies looked at aspects of the various lunar missions NASA has planned over time, including the prior Constellation program and Journey to Mars effort. A HEOMD official responsible for mission directorate analyses said that the studies ranged from quick turn-around analyses to long-term, thorough studies. NASA officials identified 12 studies completed since the conclusion of the Constellation program in 2010 that informed their decision to build Gateway and other aspects of the lunar architecture.[32] The studies varied in focus, ranging from a study on the overall framework for a mission to Mars to a study exclusively on the human lunar landers.

We reviewed these 12 studies to determine the extent to which NASA analyzed alternatives to inform its current lunar architecture. We found that some of the studies contained detailed analyses, but had a narrow scope. For example:

- NASA conducted a study on the design of its human lunar landers that identified several alternative designs for the lander configuration, including two- and three-stage landers. The study provided an analysis on each alternative in order to compare those alternatives, given the physical constraints of SLS and commercial launch vehicles.
- HEOMD reviewed prior studies on a cislunar habitation facility conducted by internal and external partners that informed an Assessment of Alternatives for the Gateway program. At the time the mission directorate conducted this assessment, the concept was focused on the Journey to Mars effort, and mentioned lunar landers only as a potential secondary mission. The assessment analyzed various alternative configurations that Gateway might use and selected one of them based feasibility and schedule.
- NASA conducted studies on the best orbit in which to place Gateway. While these studies were robust, they did not more broadly analyze

[32]NASA, *The Evolvable Mars Campaign* (2016); *Global Exploration Roadmap* (2011); *Global Exploration Roadmap* (2013); *Global Exploration Roadmap* (2018); *Lunar Architecture Study Results* (2018); *Human Space Flight Architecture Team Overview* (2011); *Human Space Exploration Framework Summary* (2011-2012); *Options for Staging Orbits in Cislunar Space* (2015); *Targeting Cislunar Near Rectilinear Halo Orbits for Human Space Exploration* (2017); *Orbit Maintenance and Navigation of Human Spacecraft at Cislunar Near Rectilinear Halo Orbits* (2017); *Earth-Moon Near Rectilinear Halo and Butterfly Orbits for Lunar Surface Exploration* (2018); and *International Space Station Exploration Capabilities Study Team Assessment of Alternatives* (2017).

whether Gateway was the best solution to meet the mission need based on selection criteria.

The following are examples of topics that NASA could have addressed if they had analyzed alternatives with a broader scope:

- **Assessing commercial alternatives to SLS and Orion for a human landing on the Moon.** Each of the studies assumes the use of SLS and the Orion capsule in order to conduct the required mission. A HEOMD official told us that they did not assess commercial alternatives to SLS and Orion because commercial alternatives are not available. If commercial technology to replace SLS and Orion becomes available, the official said NASA can on-ramp those options if SLS and Orion are not delivered on time.
- **Assessing how a more capable SLS could have affected the lunar architecture.** NASA did not assess whether refocusing investment on more capable versions of its current programs, including SLS, might affect risk, cost, and schedule for a lunar landing mission. For example, developing a more capable SLS earlier may have enabled NASA to propose a different lunar lander design or to launch components of the architecture in fewer launches. In the study on the design of its human lunar landers, NASA assumed that a more capable version of SLS would not be available until at least 2028, and therefore did not assess using it as a part of its architecture. Further, at the time of the study in 2018, NASA was unsure it would have enough SLS core stages available to utilize them for any components of the architecture other than to transport crew.
- **Identifying alternatives to a lunar landing without using Gateway.** All of the studies assumed the use of Gateway or similar capability as opposed to a capability that would take astronauts directly to the lunar surface. A HEOMD official told us that NASA did not assess architectures without Gateway because they planned to utilize SLS and Orion, and NASA did not design the Orion capsule for a direct-to-moon landing. However, a HEOMD official provided us with a quick turn-around analysis that NASA conducted in 2019, after NASA initiated the Gateway program, in response to questions about alternative lunar architectures. This analysis compared a lunar landing from Gateway to a landing without Gateway and found that NASA would have to upgrade the Orion Capsule to have a direct-to-moon landing, which would increase the cost and development time of the program. As a result, the analysis concluded that a lunar landing using Gateway was the superior option. Additionally, officials said

Gateway helped develop an architecture that was sustainable and could contribute to a mission to Mars.

In addition, only one of the studies focused on a lunar landing mission because NASA completed most of the studies prior to the December 2017 Space Policy Directive-1. NASA officials stated that this is because they were told not to analyze a lunar landing during the previous administration. As a result, none of these studies represents a comprehensive assessment for NASA's current plans to return to the Moon and are, in total, missing information on potential alternatives.

While conducting a formal analysis of alternatives for the lunar architecture is no longer viable given NASA's schedule, by not having such an analysis NASA is ill-equipped to consider other alternatives as off-ramps if the current lunar architecture plans run into delays. Further, none of the studies contained a life-cycle cost estimate and without this, NASA does not know the costs of its architecture or of potential alternatives.

In October 2019, NASA officials stated they had begun to develop an Architecture Campaign Document, which would provide a summary of the studies and analyses that have informed NASA's lunar architecture. However, this document was still in draft form at the time of our review and officials did not commit to a completion date. Until NASA completes this summary, it will not have a cohesive document outlining the rationale for how it selected its current lunar architecture and lunar programs.

Lastly, the practice of formally assessing alternatives is a beneficial practice for future architectures and programs. However, NASA policy and guidance describe an analysis of alternatives as a tool, but does not require officials to analyze alternatives prior to starting work to develop a system architecture or initiating directed missions.[33] NASA may analyze alternatives for an architecture, program, project, or specific design or capability, but conducting a formal analysis of alternatives is optional. Without a requirement to conduct an analysis of alternatives prior to

[33]NASA describes an analysis of alternatives as a formal analysis method that compares alternative approaches by estimating their ability to satisfy mission requirements through an effectiveness analysis and by estimating their life-cycle costs through cost analysis. A directed mission is generated in a top-down process from the agency strategic goals and through the strategic acquisition planning process. This is in contrast to a competed mission, which is opened up to a larger community for conceptualization and definition through a Request for Proposals or competitive selection process.

NASA authorizing the initial planning of a program, NASA could miss opportunities to move forward with a more viable architecture or program to meet mission needs in the future. For a new architecture or large programs that require a lot of investment, such as future exploration efforts including Mars, conducting an analysis of alternatives would better position NASA to build a sound business case, justify and document its decisions, and advocate for its plans.

Conclusions

Effectively executing the Artemis III mission will require extensive coordination within NASA and its commercial partners, and for each individual program to meet aggressive development time frames. As NASA continues to develop its architecture and program schedules, it will be important that the agency use program management tools and practices to set these new programs up for success. Ensuring that NASA identifies points in time to conduct synchronization reviews, that the role of the proposed Lunar Exploration Control Board in these reviews is understood, and that programs are prepared with the necessary information to make the reviews successful will help NASA mitigate the risk of discovering integration challenges across the lunar programs. The reviews could be a helpful checkpoint on the agency's progress towards meeting the aggressive timeline of the Artemis III mission. Further, ensuring that the Gateway program has an integrated schedule early on will help the program plan work to meet critical deadlines and avoid unnecessary rework due to the misalignment of requirements or design changes.

To date, NASA has provided decision makers with limited cost information to inform decisions on the overall lunar investment. Without an overall cost estimate for the Artemis III mission, NASA is asking Congress to appropriate additional funding to meet a 2024 lunar deadline without having information available on how much it will cost in total to support such plans. Further, NASA senior leadership made a decision that resulted in limiting information regarding the probability of the Gateway program meeting cost and schedule estimates to support the 2024 lunar landing. Requiring the program to conduct a joint cost and schedule confidence level analysis would help to determine whether NASA can meet its lunar goal and whether it has resources to be able to do so.

NASA will continue to have many stakeholders interested in its human space exploration plans, which requires NASA to establish a lunar architecture and programs that the agency can defend over time and to demonstrate that it has a solid business case. However, NASA is ill-

positioned to explain how it arrived at its current lunar architecture without a comprehensive assessment that documents how NASA decided that its current plans are the best way to meet the agency's long-term lunar exploration goals. NASA has taken a positive step by planning to create a summary of the studies and analyses that informed its lunar architecture, but has not committed to a date to finalize it. Finally, ensuring that NASA conducts a formal analysis of alternatives for future strategic missions and architectures, including as it further develops its plans for a human mission to Mars, will better position the agency to consistently and reliably select alternatives that best meet the mission need.

Recommendations for Executive Action

We are making the following six recommendations to NASA.

The NASA Administrator should ensure that the NASA Associate Administrator for Human Exploration and Operations directs the Advanced Exploration Systems division to define and determine a schedule for synchronization reviews, including the role of the proposed Lunar Exploration Control Board, to help ensure that requirements between mission and program levels are reconciled. (Recommendation 1)

The NASA Administrator should ensure that the NASA Associate Administrator for Human Exploration and Operations directs the Gateway program to conduct a joint cost and schedule confidence level at the program level for the Artemis III mission. (Recommendation 2)

The NASA Administrator should ensure that the NASA Associate Administrator for Human Exploration and Operations directs the Gateway program to update its overall schedule for 2024 to add a KDP II to occur before system integration. (Recommendation 3)

The NASA Administrator should ensure that the NASA Associate Administrator for Human Exploration and Operations creates a life-cycle cost estimate for the Artemis III mission. (Recommendation 4)

The NASA Administrator should ensure that the NASA Associate Administrator for Human Exploration and Operations directs the Advanced Exploration Systems division to commit to a completion date and finalize a cohesive document outlining the rationale for selecting its current lunar architecture and lunar programs. (Recommendation 5)

The NASA Administrator should ensure that the Office of the Chief Engineer determines under what conditions it is appropriate to complete

an analysis of alternatives, particularly when there are multiple pathways—including architectures or programs—that NASA could pursue in the future, and document the justification for not completing an analysis. (Recommendation 6)

Agency Comments and Our Evaluation

We provided a draft of this report to NASA for comment. In written comments, NASA agreed with our six recommendations. NASA provided estimated dates of completion for all of the recommendations ranging from April 2020 to September 2021. The comments are reprinted in appendix I. NASA also provided technical comments, which have been addressed in the report, as appropriate.

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

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

Cristina T. Chaplain
Director, Contracting and National Security Acquisitions

Appendix I: Comments from the National Aeronautics and Space Administration

National Aeronautics and Space Administration

Headquarters
Washington, DC 20546-0001

DEC 11 2019

Reply to Attn of: Human Exploration and Operations Mission Directorate

Ms. Cristina T. Chaplain
Director
Contracting and National Security Acquisitions
United States Government Accountability Office
Washington, DC 20548

Dear Ms. Chaplain:

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: Opportunities Exist to Strengthen Analyses and Plans for Moon Landing" (GAO-20-68) dated November 1, 2019. 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.

Progress made in the Advanced Exploration Systems (AES) and Exploration Systems Development (ESD) programs represents a significant achievement for the Agency and the Nation's future. The systems development, fabrication, and assembly work being performed today is setting the basis for a series of missions that will lead to the Moon, Mars, and beyond. We appreciate GAO's acknowledgement that the Gateway and Human Landing System (HLS) programs are in formulation and, therefore, that program and enterprise plans are still in development. NASA is particularly focused on the need for strong technical integration (in the form of interface requirements documents, shared boards, etc.) between the AES and ESD programs as well as between the AES and ESD enterprises. While GAO is reviewing these programs at a much earlier stage of their life cycle than is typical, NASA recognizes that Congress has a strong interest in the overall success of the Artemis program. NASA also appreciates GAO's recognition of the positive steps that NASA has taken to increase the visibility into cost and schedule performance of these programs.

In the draft report, GAO makes six recommendations to NASA intended to define and schedule reviews that align requirements across lunar programs, create a cost estimate for the first lunar mission, commit to a completion date, and finalize a document outlining the rationale for selecting the current lunar plans. Specifically, GAO recommends the following:

Recommendation 1: The NASA Administrator should ensure that the NASA Associate Administrator for Human Exploration and Operations directs the

Advanced Exploration Systems division to define and determine a schedule for synchronization reviews, including the role of the proposed Lunar Exploration Control Board, to help ensure that requirements between mission and program levels are reconciled.

Management's Response: NASA concurs with the recommendation. NASA recognizes that the complexity of the technical and programmatic interactions between the Gateway and HLS programs requires strong cross-program integration to ensure mission success and meet Agency cost and schedule commitments. The Gateway and HLS programs are in early formulation and therefore in the process of developing their program and life cycle review plans, under the auspices and oversight of the AES enterprise. Cross-program integration and synchronization will be fundamental tenets of these plans. In practice, each program has representatives from the other AES programs as well as the AES enterprise on their control boards. Through the AES Control Board and other processes as appropriate, AES will review program life cycle review plans and, where necessary, direct the programs to include in those plans specific cross-program and enterprise level products and analyses needed to ensure enterprise and program requirements are reconciled across the mission. After approving program plans, AES may, if necessary and in concert with the Office of the Chief Engineer and other Agency authorities, decide to conduct additional, enterprise-level reviews to close any remaining life cycle integration gaps.

Estimated Completion Date: NASA currently plans to approve AES program (and, if necessary, enterprise-level) life cycle review plans by April 2020.

Recommendation 2: The NASA Administrator should ensure that the NASA Associate Administrator for Human Exploration and Operations directs the Gateway program to conduct a joint cost and schedule confidence level at the program level for the Artemis III mission.

Management's Response: NASA concurs with the recommendation. The Gateway program will conduct a series of project and program-level reviews and assessments (including a joint cost and schedule confidence level, JCL, analysis or equivalent) of the Gateway Phase 1 configuration to support crewed lunar operations as part of the program's preparation for Agency key decision point (KDP). Consistent with the Gateway program tailoring approach that was approved by the Agency on August 19, 2019, Gateway cost and schedule commitments will be made at the project level.

Estimated Completion Date: Gateway assessments (including a program cost estimate and schedule risk analysis) will be prepared to support the program KDP-0 review, currently scheduled for July 2020. A program-level JCL analysis (informed by each of the Gateway Phase 1 project JCLs) will be conducted to support the program KDP-1 review, currently scheduled for July 2021.

Recommendation 3: The NASA Administrator should ensure that the NASA Associate Administrator for Human Exploration and Operations directs the Gateway program to update its overall schedule for 2024 and add a KDP II before system integration.

Management's Response: NASA concurs with the recommendation. Consistent with the Gateway program tailoring approach that was approved by the Agency on August 19, 2019, the Gateway program is planning on conducting synchronization reviews following a program KDP-0 in 2020 and a KDP-I in 2021. The plan and schedule for those future reviews will be presented at the KDP-I review currently scheduled for July 2021. Following KDP-I, the next review will meet the intent of a KDP-II, with any potential tailoring approved by the Agency convening authorities and as documented in the Gateway program review terms of reference.

Estimated Completion Date: NASA currently plans to approve the Gateway review plan by April 2020.

Recommendation 4: The NASA Administrator should ensure that the NASA Associate Administrator for Human Exploration and Operations creates a life-cycle cost estimate for the Artemis III mission.

Management's Response: NASA concurs with the recommendation. For Gateway, NASA will establish baseline cost and schedule commitments for the Gateway Phase 1 projects (Power and Propulsion Element, Habitation and Logistics Outpost, Gateway Logistics Services, and Surface Suits) that will support the 2024 mission. NASA will also establish a baseline cost and schedule commitment for the Human Landing System program through demonstration of a human lunar landing capability on the 2024 mission. NASA will make cost and schedule commitments for these program consistent with direction provided in NASA Procedural Requirements 7120.5E, "NASA Space Flight Program and Project Management Requirements." Exploration Systems Development contracts that include support for Artemis III are currently in negotiation.

Estimated Completion Date: NASA will provide a preliminary cost estimate for the Artemis III mission by the end of calendar year 2020, once the Agency makes baseline cost and schedule commitments for the Human Landing System (currently planned for September 2020), the contracts for Exploration Systems Development programs that include support for Artemis III are signed (currently planned for the end of calendar year 2020), and the Gateway program completes Key Decision Point (currently planned for July 2020) NASA will provide an updated cost estimate for the Artemis III mission once the Agency makes baseline cost and schedule commitments for the Gateway projects (currently planned for Spring 2021).

Recommendation 5: The NASA Administrator should ensure that the NASA Associate Administrator for Human Exploration and Operations direct the Advanced Exploration Systems division to commit to a completion date and finalize a cohesive document outlining the rationale for selecting its current lunar architecture and lunar programs.

Management's Response: NASA concurs with the recommendation. NASA is developing a document that will summarize the trades and architectural studies which constituted an analysis of architectural alternatives and resulted in the Agency's decision to baseline the current lunar architecture and associated programs. The document will be reviewed by the new Associate Administrator for Human Exploration and Operations to ensure alignment with any changes to the plan to better focus on mission success and minimize overall program risk.

Estimated Completion Date: NASA currently plans to complete this document by July 2020.

Recommendation 6: The NASA Associate Administrator should ensure that the Office of Chief Engineer determines under what conditions it is appropriate to complete an analysis of alternatives, particularly when there are multiple pathways – including architectures or programs – that NASA could pursue in the future, and document the justification for not completing an analysis.

Management's Response: NASA concurs with the recommendation.

NASA anticipates that the Moon to Mars campaign will evolve within a dynamic environment – characterized by emerging capabilities, new technologies, new partnership opportunities, new scientific discoveries, and changing available resources – that interact in complex (and currently unknown) ways. In this environment, NASA anticipates a need to continually assess the Agency's exploration strategy and architecture in light of new information and emerging opportunities.

Consistent with NASA Procedural Requirements 7120.5E, "NASA Space Flight Program and Project Management Requirements," for new programs NASA will continue to perform an analysis of alternatives to assist in the formulation of sound program plans that contains project elements, requirements, schedules, and time-phased cost plans. Consistent with NASA policy, including NASA Policy Directive 1000.0B, "NASA Governance and Strategic Management Handbook," NASA may tailor the analysis of alternatives process to meet the needs of a specific program, project or activity. Such strategies will be documented in program formulation and acquisition products that are approved by the appropriate Agency authority consistent with NASA policies and procedures. Additional clarifying guidance for the conduct of analyses of alternatives for new programs will be provided in the next update to NPR 7120.5.

For the Moon to Mars architecture, NASA will establish a Moon to Mars campaign strategy. The campaign strategy will complement the document

referenced in response to Recommendation 5, which will describe the trades and architectural studies which constituted an analysis of architectural alternatives and resulted in the Agency's decision to baseline the current lunar architecture and associated programs. NASA will develop a mechanism to ensure configuration control of the campaign strategy within the Agency governance model, including leveraging the Federated Board composed of Deputy Associate Administrators from the Human Exploration and Operations, Science, and Space Technology Mission Directorates, as well as other organizations including the Office of the Chief Engineer. The purpose of this campaign strategy will be to serve as a point of departure for conducting technical and programmatic trades of the campaign architecture (including analyses of alternatives) and informing near-term program and budget decisions.

Estimated Completion Date: NASA currently plans to propose closing this action by September 2021, after the Agency releases the initial Moon to Mars campaign strategy (currently planned for April 2020) and a draft update to 7120.5, to include language clarifying the use of alternative analyses for new programs (currently planned for September 2021).

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 Michelle Bascoe on (202) 358-1574.

Sincerely,

Douglas L. Loverro
Associate Administrator
for Human Explorations and Operations

for R.R.

Ralph R. Roe Jr.
NASA Chief Engineer

Appendix II: GAO Contact and Staff Acknowledgments

GAO contact

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

Staff Acknowledgments

In addition to the contact named above, Molly Traci, Assistant Director; Katie Bassion; Lorraine Ettaro; Laura Greifner; Anna Irvine, Erin Kennedy; Jason Lee, Assistant Director; Jennifer Leotta, Assistant Director; Ryan Lester; Dennis Mayo; Sylvia Schatz; Roxanna Sun; Jay Tallon, Assistant Director; Alyssa Weir; and Tonya Woodbury made significant contributions to this report.