ARTEMIS PROGRAMS

NASA Should Document and Communicate Plans to Address Gateway's Mass Risk

Report to Congressional Committees

July 2024
GAO-24-106878
United States Government Accountability Office

Accessible Version

GAO Highlights

View GAO-24-106878. For more information, contact William Russell at (202) 512-4841 or RussellW@gao.gov.
Highlights of GAO-24-106878, a report to congressional committees
July 2024

ARTEMIS PROGRAMS

NASA Should Document and Communicate Plans to Address Gateway's Mass Risk

Why GAO Did This Study

NASA plans to return astronauts to the moon to make new scientific discoveries, generate economic benefits, and inspire a new generation. To help support crewed lunar landings, NASA plans to use the Gateway as a habitat and safe work environment for astronauts. NASA plans to first use the Gateway to house crew during the Artemis IV lunar landing mission, which NASA is planning to conduct in September 2028. NASA tracks the Gateway program's progress via cost and schedule commitments.

A House Report contains a provision for GAO to continue reviewing NASA's lunar-focused programs. This report focuses on the Gateway program and its NASA-led development projects. It addresses (1) the Gateway program's plans to update the initial capability's cost and schedule analysis; (2) the extent to which the Gateway program made progress with its U.S.-led projects needed for the Artemis IV mission and is addressing project risks; and (3) NASA's process for determining how it will use the Gateway beyond Artemis IV, including for Mars missions.

GAO analyzed NASA documentation and interviewed officials on the Gateway program's cost, schedule, risks, and role in the Artemis architecture.

What GAO Recommends

GAO is making one recommendation, that NASA should ensure that the Gateway program documents and communicates an overall mass management plan before its next program-level review. NASA agreed with GAO's recommendation.

What GAO Found

The National Aeronautics and Space Administration (NASA) plans to build a sustained human lunar presence and ultimately travel to Mars through a series of missions known as Artemis. For Artemis IV, the agency is developing the Gateway—the first space station planned to orbit the moon. NASA committed to launching the Gateway initial capability by December 2027 at a cost of $5.3 billion. The launch will include the first components of the Gateway—the Power and Propulsion Element (PPE) and the Habitation and Logistics Outpost (HALO).

The Gateway program plans to update the analysis it used to inform its cost and schedule commitments at a fall 2024 program-level review. This will help determine the feasibility of the Artemis IV mission date. To reach lunar orbit and ensure all systems work as planned, the PPE and HALO need to launch at least 12 months before the Artemis IV mission, or 3 months earlier than Gateway's current committed date. NASA officials said the program plans to work to an accelerated, to-be-determined date that would provide more schedule flexibility.

Gateway Program Launch Date Options for Artemis IV Mission

Source: GAO analysis of NASA documentation. | GAO-24-106878

The Gateway program's projects—including PPE and HALO—made varying degrees of progress over the last year. However, the PPE and HALO projects face several significant challenges. For example, their combined mass is greater than their mass target. Mass is one of many factors that the program considers in its overall design. If they cannot meet their mass target, it may affect their ability to reach the correct lunar orbit. The program has not yet documented an overall mass management plan, which would describe the program's mass reduction approach and priorities for key trade-off decisions. Documenting and communicating this plan will help to ensure that the program and its projects agree on how to address the mass challenge.

NASA held two reviews in 2023 to break down high-level Artemis exploration objectives and goals into the programs, projects, or systems needed to achieve them. So far, NASA has used these reviews to assign roles to the Gateway that align to goals of the earlier Artemis missions, like returning humans to the moon. NASA plans to use upcoming reviews to make key decisions related to Mars missions, which could inform how NASA might use the Gateway in the future.

Contents

Abbreviations

ACR	Architecture Concept Review
CMV	comanifested vehicle
DSL	Deep Space Logistics
ESDMD	Exploration Systems Development Mission Directorate
ESPRIT-RM	European System Providing Refueling, Infrastructure, and Telecommunications Refueler Module
HALO	Habitation and Logistics Outpost
HLS	Human Landing System
I-HAB	International Habitat
JCL	joint cost and schedule confidence level
KDP	key decision point
M2M	Moon to Mars
NASA	National Aeronautics and Space Administration
NRHO	near rectilinear halo orbit
Orion	Orion Multi-Purpose Crew Vehicle
PPE	Power and Propulsion Element
SAO	Strategy and Architecture Office
SEP	Solar Electric Propulsion
SLS	Space Launch System
SpaceX	Space Exploration Technologies Corporation

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

July 31, 2024

Congressional Committees

The National Aeronautics and Space Administration (NASA) plans to return astronauts to the moon, build a sustainable lunar presence over the next decade, and ultimately travel to Mars through a series of missions known collectively as Artemis. As part of these plans, the agency is developing the Gateway—a small space station planned to orbit the moon. The Gateway will serve as a research platform, a staging point for human and robotic exploration in deep space, and a technology test bed for future Mars exploration. The Gateway is the central aggregation point for the Artemis IV lunar landing mission, currently planned for September 2028. During the mission, the Gateway will house crew before, during, and after the lunar landing. Between fiscal years 2018 and 2029, NASA anticipates spending over $7 billion to build and operate the Gateway.

The Gateway program is composed of three U.S.-led projects: Power and Propulsion Element (PPE), Habitation and Logistics Outpost (HALO), and Deep Space Logistics (DSL). Each of these projects is developing a module that will provide unique capabilities for the Gateway. The PPE and HALO make up the Gateway's initial capability. These two modules together can support a crew on the Gateway, with the PPE providing the power and propulsion and the HALO providing a space for crew to live. NASA plans to launch the PPE and HALO together prior to the Artemis IV mission, so that the agency is ready to support a crew during the mission. In addition, NASA plans to launch cargo into lunar orbit on a logistics vehicle to support crewed missions to the Gateway, including for the Artemis IV mission.[1] Over time, NASA, and its international partners plan to add modules to the Gateway to support later Artemis missions.

The House Report 117-395 accompanying the Commerce, Justice, Science, and Related Agencies Appropriations bill, 2023 contains a provision for GAO to conduct in-depth reviews of NASA's lunar-focused programs. This report focuses on the Gateway program and its U.S.-led development projects. This report addresses (1) the Gateway program's plans for updating its cost and schedule analysis for the initial capability; (2) the extent to which the Gateway program has made progress with the PPE, HALO, and DSL vehicle needed for the Artemis IV mission in 2028 and is addressing project risks; and (3) NASA's process for determining how it will use the Gateway to support missions beyond Artemis IV, including Mars missions.

To determine the Gateway program's plans to update its cost and schedule analysis for the initial capability, we reviewed NASA and program documentation, including documentation of the Gateway program's initial capability cost and schedule analysis. We interviewed Gateway and Moon to Mars (M2M) program officials to understand the agency's process for developing and approving the cost and schedule baselines for the initial capability and to identify when the program aims to update the cost and schedule analysis. We also reviewed NASA documentation and interviewed program officials to determine when the Gateway program would need to launch the PPE and HALO together for the Gateway to be ready to support the Artemis IV mission. We refer to this date as the need launch readiness date in this report.

[1]The DSL project manages a contract that provides commercial end-to-end services for the delivery of cargo, supplies, and other necessities on logistics vehicles for crew.

To determine the progress of the Gateway program and HALO, PPE, and DSL projects toward supporting the Artemis IV mission and their plans to address project risks, we assessed Gateway program and project documentation and interviewed program and project officials. We reviewed the documentation and interviewed officials to determine how they plan to address technical and design challenges and top risks. We also interviewed M2M program, Gateway program, and HALO project officials to understand how the Gateway fits into the concept of operations for the Artemis IV mission and supports the planned September 2028 mission date. We compared program plans to address technical and design risks against NASA policy and guidance related to program management and systems engineering. We also compared these plans against our best practices for technology readiness and product development and federal internal control standards.[2]

To understand the agency's processes for determining how it will use the Gateway to support missions beyond Artemis IV, we examined NASA's architecture review process. This process is intended to map high-level M2M objectives to the specific elements that will support science and exploration goals. We reviewed documentation from the first two architecture concept review cycles, M2M and Gateway program requirements documents, and other related documentation. We interviewed M2M program, Strategy and Architecture Office, and Gateway program officials to discuss the architecture concept review process, and the extent to which the Gateway's role in missions beyond Artemis IV has been determined, among other topics.

See appendix I for more information on our objectives, scope, and methodology.

We conducted this performance audit from May 2023 to July 2024 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

The Gateway and Its Role in the Artemis IV Mission

The Gateway will help support NASA's long-term lunar exploration goals to create a sustained presence on and around the moon.[3] NASA plans to return astronauts to the moon to make new scientific discoveries, generate economic benefits, and inspire a new generation. NASA first plans to use the Gateway to house crew during the Artemis IV mission. For Artemis IV, NASA plans to field an initial configuration of the Gateway

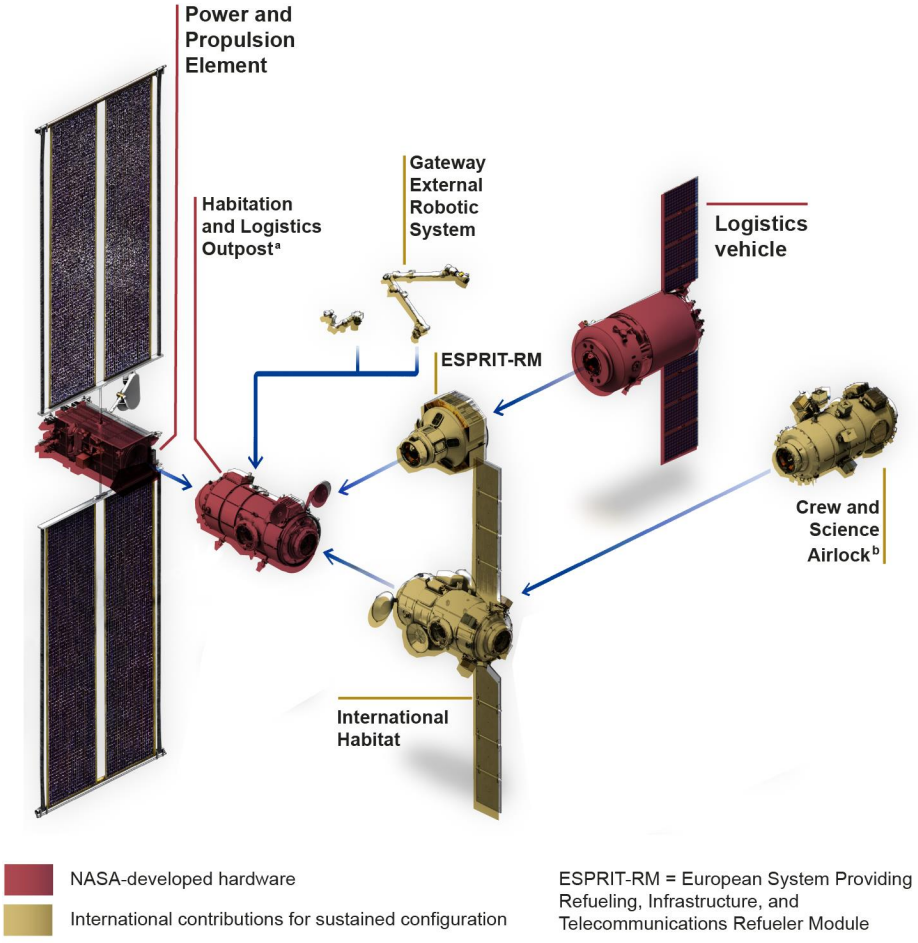
[2]GAO, *Standards for Internal Control in the Federal Government*, GAO-14-704G (Washington, D.C.: September 2014); *Best Practices: Using a Knowledge-Based Approach to Improve Weapon Acquisition*, GAO-04-386SP (Washington, D.C.: Jan. 1, 2004); and *Best Practices: Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes*, GAO-02-701 (Washington, D.C.: July 15, 2002).

[3]NASA, in conjunction with its international partners, also plans to conduct multiple scientific experiments as the Gateway's PPE and HALO transit to the moon.

consisting of three U.S.-developed elements. NASA will then add four additional elements contributed by international partners until it reaches what it calls Gateway's sustained configuration.[4]

NASA plans to use the Gateway in multiple ways to support Artemis missions. For example, it is to serve as a habitat and safe work environment for astronauts and as a communications relay between the lunar surface and Earth. It will also facilitate lunar landings. Figure 1 shows the planned Gateway sustained configuration.

Figure 1: Illustration of the Gateway Sustained Configuration



Source: GAO analysis of Gateway program documentation (data); NASA (image). | GAO-24-106878

[a]The Habitation and Logistics Outpost includes hardware provided by international partners.

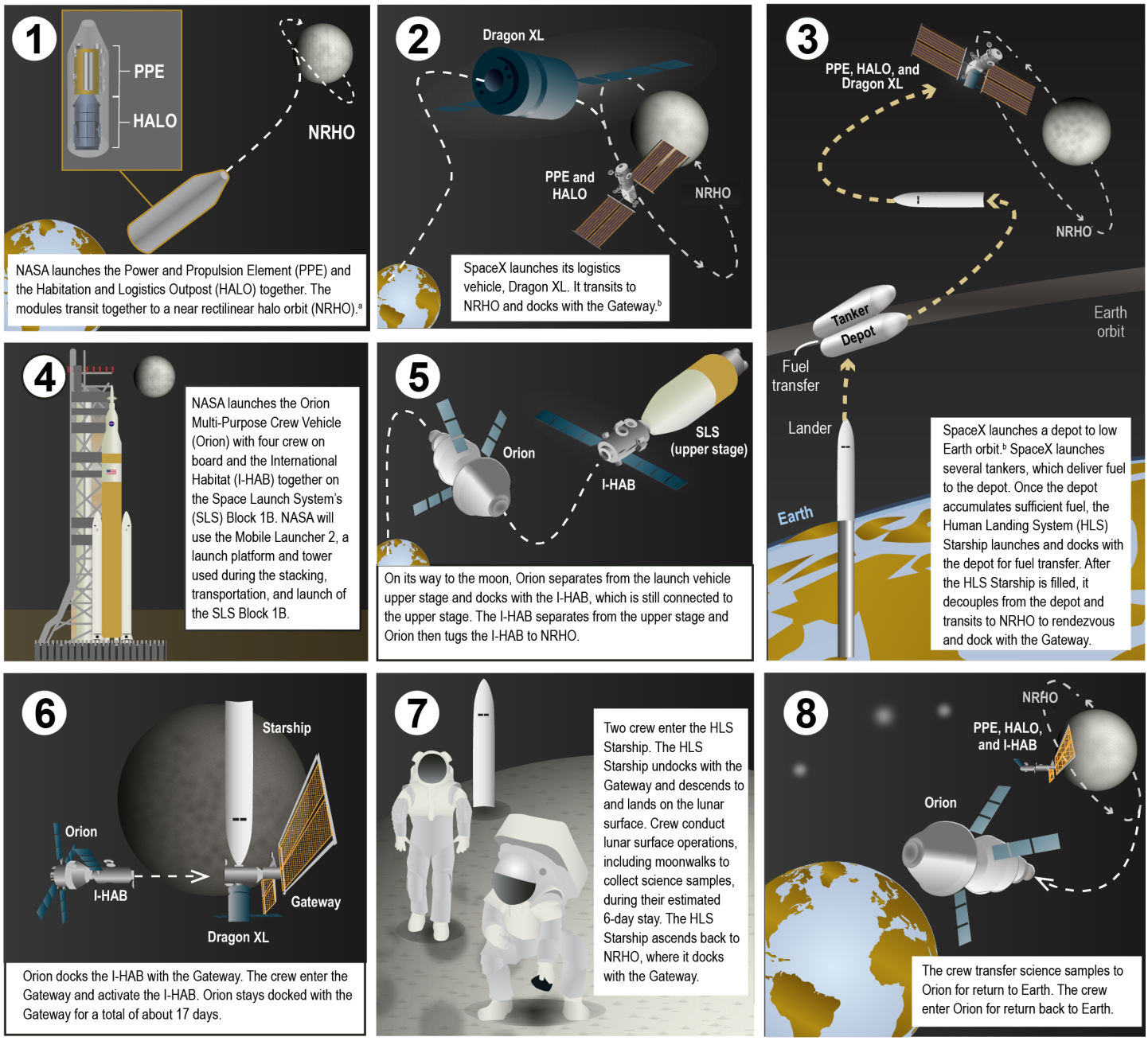
[b]The illustration of the Crew and Science Airlock is based on a government reference design.

[4]NASA plans to add modules developed by international partners to the Gateway during the Artemis IV, V, and VI missions to create the sustained configuration. The sustained configuration adds additional capabilities to support longer crewed missions and additional science operations. For example, NASA signed agreements with the European Space Agency to provide an additional habitation module and a refueler module, the Canadian Space Agency for a robotic arm, and the Mohammed Bin Rashid Space Centre of the United Arab Emirates for a crew and science airlock. NASA also signed an agreement with the Government of Japan to provide life support systems and batteries and another logistics resupply vehicle.

NASA first plans to use the Gateway in the Artemis IV mission. This mission will be complex because NASA will need to coordinate across seven NASA programs, multiple contractors that support those programs, and international partners to execute the mission. It will also be the first launch of an upgraded version of the Space Launch System rocket. During the mission, astronauts will arrive at the Gateway on the Orion Multi-purpose Crew Vehicle (Orion), help integrate the International Habitat with the HALO, and conduct a lunar landing.[5] The crew will transfer into a human landing system for transport to the lunar surface and back. After returning to the Gateway, the crew will return to Earth aboard the Orion crew capsule. See figure 2 for more details on key Gateway events in the concept of operations for the Artemis IV mission.

[5]The International Habitat will provide additional living space and additional life support systems for crew on the Gateway, which will enable longer crewed missions.

Figure 2: Key Gateway Events in the Artemis IV Mission Concept of Operations



Source: GAO analysis of NASA and SpaceX information (data); GAO (illustration); GAO illustration of Starship based on SpaceX image. | GAO-24-106878

[a]Near rectilinear halo orbit is a 1-week lunar orbit balanced between Earth's and the moon's gravity. This orbit enables global lunar access and promotes access to the lunar poles.

[b]NASA has not yet finalized the order of events in steps 2 and 3.

NASA is partnering with industry for the Gateway's U.S.-led projects. NASA awarded contracts to Maxar Space Systems for the PPE, Northrop Grumman for the HALO, and Space Exploration Technologies Corporation

(SpaceX) for the logistics vehicle. See table 1 for project descriptions and details on the acquisition strategy the agency is using for each project.

Table 1: U.S.-led Gateway Projects, Project Descriptions, and Acquisition Strategies

Project	Description	Acquisition strategy
Power and Propulsion Element (PPE)	The PPE is to provide the Gateway with power, communications, and the ability to change orbits, among other things.	In May 2019, NASA awarded a firm-fixed price contract to Maxar Space Systems to develop, build, and demonstrate power, propulsion, and communications capabilities. The initial value of the contract was $375 million. As of July 2023, the total value of the contract was over $1 billion. The contract price has grown in large part due to requirements changes and NASA's February 2020 decision to launch the HALO and PPE together.
Habitation and Logistics Outpost (HALO)	The HALO is to provide docking ports for visiting vehicles, space for habitation and storage, and the systems to support crew on board the Gateway.	In June 2020, NASA definitized an undefinitized contract action into a cost-plus-incentive-fee contract with Northrop Grumman Space to develop the preliminary design for the HALO. At that time, the cost of the contract was valued at $187 million. In July 2021, NASA incorporated a firm-fixed-price contract modification to add work for the HALO's manufacturing and integration with PPE, among other things. This modification increased the total value of the contract to nearly $1.3 billion.
Deep Space Logistics (DSL)	The DSL project manages the Gateway Logistics Services contract, which provides commercial end-to-end services to the Gateway for cargo deliveries, supplies, stowage, and trash disposal prior to crew arrival to maximize the length of crew stays on the Gateway.	In March 2020, NASA awarded an initial indefinite delivery, indefinite quantity contract to Space Exploration Technologies Corporation (SpaceX). The contract guarantees the company a minimum of two logistics missions. Each mission is a firm-fixed-price task order off the contract. SpaceX is responsible for building, integrating, and operating the logistics vehicle. Under the contract, NASA may award task orders to other contractors to compete to provide logistics services for future missions. These contractors would provide similar services as SpaceX. The maximum value of the contract for all missions is $7 billion.

Source: GAO analysis of NASA documentation and contracts. | GAO-24-106878

The PPE project relies on another NASA project—Solar Electric Propulsion (SEP)—to develop, build, and qualify high-power solar electric propulsion thrusters. The SEP project is responsible for working with Aerojet Rocketdyne to build and test two qualification thrusters and three flight thrusters, which the SEP project will provide to the PPE project as government furnished equipment.

NASA Acquisition Life Cycle

The Gateway program is NASA's first tightly coupled program, meaning it is composed of multiple projects that work together to complete the program's mission. The acquisition life cycle for a tightly coupled program closely resembles the life cycle for a spaceflight project, which the PPE, HALO, and DSL projects follow. Life cycles for both consist of two phases, formulation and implementation. The formulation phase takes a program or project from concept to preliminary design, and the implementation phase includes building, launching, and operating the system, among other activities. In addition, both programs and projects hold key decision points

(KDP) where senior NASA officials approve programs and projects to move to the next phase. For example, tightly coupled programs hold a KDP I review and projects hold a KDP C review before moving from the formulation to the implementation phase.

In December 2023, NASA approved the Gateway initial capability to enter the implementation phase after completing a KDP I review. This KDP I review also served as the KDP C reviews that approved the PPE and HALO projects to enter their implementation phases. The Gateway program plans to hold a separate KDP C review for the DSL project and establish cost and schedule baselines for the development of the first logistics vehicle.

As part of the initial capability review, NASA established the agency baseline commitment for the Gateway initial capability in a December 2023 decision memorandum. The Gateway initial capability's cost baseline is $5.3 billion and the schedule baseline is December 2027.[6] This represents the cost and schedule baselines against which external stakeholders, such as Congress and the Office of Management and Budget, measure the agency's performance. We refer to December 2027 as the baseline launch readiness date in this report. NASA plans to work to an earlier launch readiness date, which we refer to as the accelerated launch readiness date.

To inform the baselines, NASA policy requires each program and project with a life-cycle cost estimated to be greater than $250 million to 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 the end of the system assembly, integration and test, and launch phase. The JCL incorporates and quantifies known risks, assesses the effects of cost and schedule on the estimate as of the time the JCL is conducted, and addresses available annual resources. The results of a JCL indicate the probability of a program or project's success in meeting cost and schedule targets. For example, NASA estimated a 70 percent probability of the Gateway program meeting its cost baseline and the baseline launch readiness date. Typically, the agency approves baselines at a 70 percent probability of the program or project meeting its cost and schedule targets.

Throughout the acquisition life cycle, the PPE, HALO, and DSL projects hold technical reviews to assess the maturity of their systems or evaluate the readiness to move to the next phase. For example:

- Near the end of the formulation phase, projects hold a preliminary design review to assess the maturity of their technologies and to determine if their designs are mature enough to proceed with the detailed design activities.

- During the implementation phase, projects hold a critical design review to determine if their designs are stable enough to support proceeding with the final design and fabrication.

- After the critical design review, projects complete a system integration review to evaluate the readiness of the project and associated supporting infrastructure to begin system assembly, integration, and test.

The Gateway program tailored these technical reviews at the program level to assess the maturity of the program across its projects and international contributions. The program calls these synchronization reviews.

[6]The cost baseline includes the costs of the PPE and HALO projects, launch vehicle, and program support for integration and launch.

The synchronization reviews focus on integrated aspects that the PPE and HALO projects do not address through their project-level reviews. The program plans to hold its critical design-informed synchronization review in September 2024.

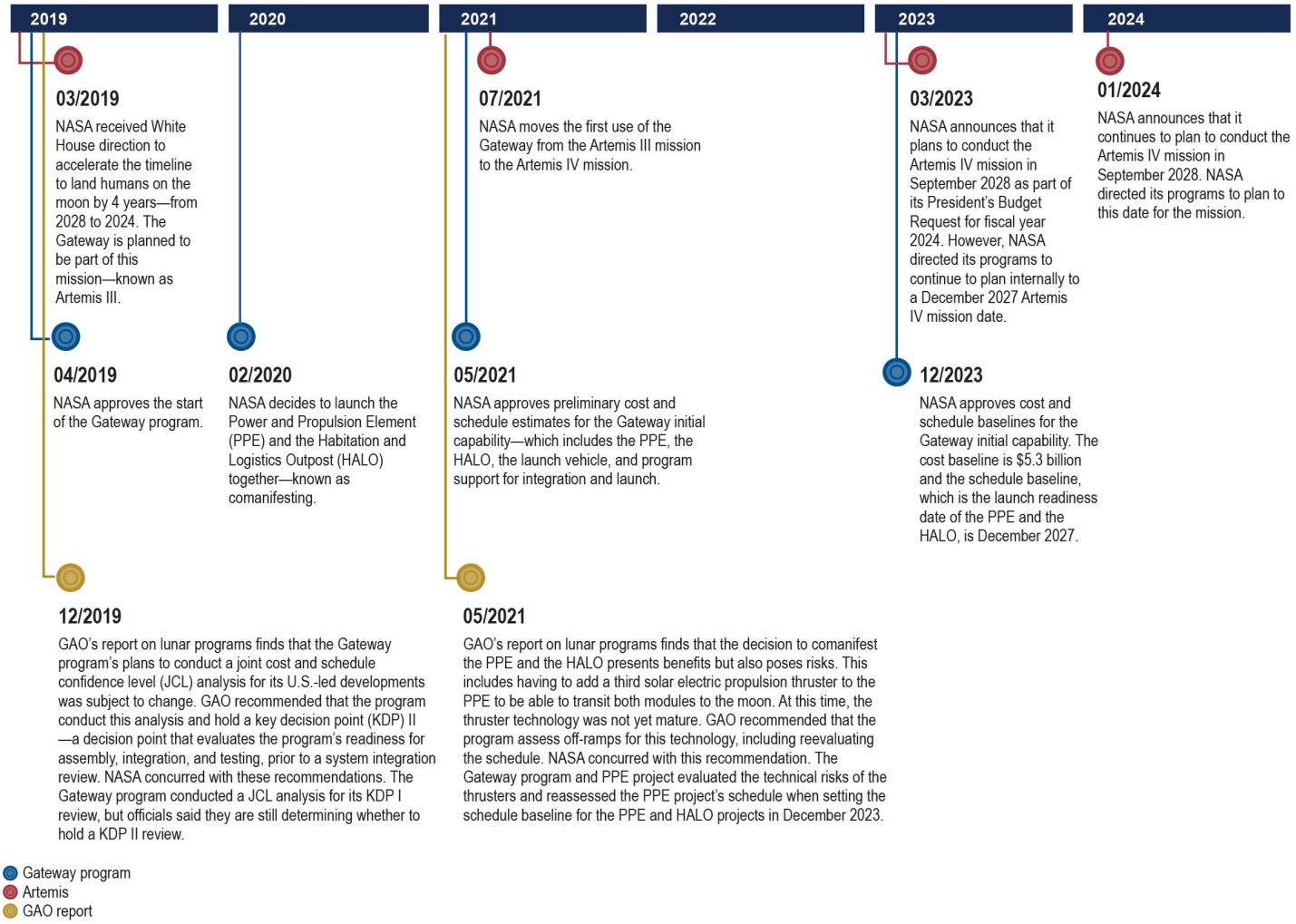
Gateway program officials said they are still deciding whether they will hold a KDP II review—a review for NASA to assess whether the program has enough margin and an acceptable level of risk to meet its cost baseline and baseline launch readiness date. In our 2019 report on lunar programs, we recommended that the Gateway program hold a KDP II review.[7] NASA concurred with our recommendation, but Gateway program officials said they are still discussing whether to hold any additional KDP reviews for the initial capability. We continue to believe the program should hold this review as the PPE and HALO projects work toward system integration and test.

Relevant GAO Reports and Key Past Artemis and Gateway Events

NASA made several changes to the Gateway program since we first began reviewing it in 2019. See figure 3 for a summary of key events and our relevant report findings and recommendations since 2019.

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

Figure 3: Key Events in the Gateway and Artemis Program's History and Related GAO Report Findings and Recommendations



Source: GAO analysis of NASA documentation; GAO (illustration). | GAO-24-106878

NASA acquisition management has been on our high-risk list since 1990.[8] As we noted in our January 2024 testimony on Artemis programs, NASA has made improvements to its acquisition management policies and practices in recent years.[9] However, it still faces challenges in its ability to manage its costliest and most complex programs, such as those that are critical to support the Artemis missions.

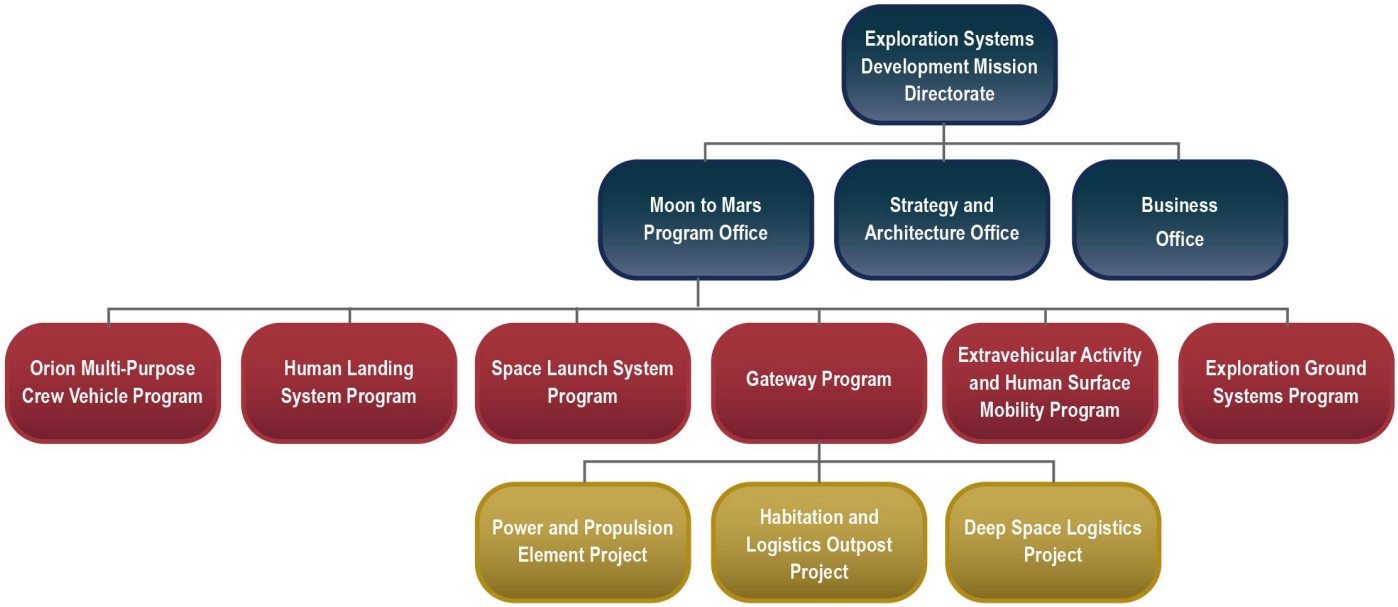
[8]GAO, *High-Risk Series: Efforts Made to Achieve Progress Need to Be Maintained and Expanded to Fully Address All Areas,* GAO-23-106203 (Washington, D.C.: Apr. 20, 2023).

[9]GAO, *NASA Artemis Programs: Lunar Landing Plans are Progressing, but Challenges Remain,* GAO-24-107249 (Washington, D.C.: Jan. 17, 2024).

Establishment of Moon to Mars Program Office and Architecture Concept Review Process

In March 2023, the NASA Administrator established the M2M program office as directed by section 10811 of the National Aeronautics and Space Administration Authorization Act.[10] Under the act, the director of the M2M program office must, among other things, have authority to manage resources, personnel, and contracts to implement the program, and direct and oversee a program-wide systems engineering and integration and integrated risk management function. The office resides within NASA's Exploration Systems Development Mission Directorate (see fig. 4).

Figure 4: NASA's Exploration Systems Development Mission Directorate Organizational Chart



Source: GAO analysis of NASA documentation. | GAO-24-106878

The M2M program office is responsible for supervising the development and operations of the individual M2M programs, including the Gateway. In addition, the program office manages risks for exploration efforts; integrates the design, engineering, operations, and budget formulation for the programs; and oversees Artemis mission preparation, training, operations, and execution.

NASA also created the Strategy and Architecture Office (SAO) within the Exploration Systems Development Mission Directorate in March 2023. The SAO works alongside the M2M program office and is responsible for defining the agency's architecture for exploration of the moon and Mars based on its M2M objectives.[11] This architecture is the agency's high-level unifying structure for its M2M exploration goals. It includes a set of rules, guidelines, and constraints that define the structure and the connections that establish how the individual parts fit and work together. The SAO integrates stakeholder input into the architecture and guides new programs

[10]NASA Authorization Act of 2022, Pub. L. No. 117-167, § 10811 (51 U.S.C. § 20302 note).

[11]NASA, *NASA's Moon to Mars Strategy and Objectives Development: A blueprint for sustained human presence and exploration throughout the Solar System*, NP-2023-03-3115-HQ (2023).

through the pre-formulation phase. Once NASA initiates these new programs, the M2M program office is responsible for their continued development through the remainder of the acquisition life cycle.

In 2022, NASA established the agency's Architecture Concept Review process—the process by which the agency plans to map high-level M2M objectives to the specific elements that will support science and exploration goals.[12] The process centers on an annual study cycle—called the strategic analysis cycle—to continually update and refine the architecture, incorporating feedback from stakeholders from within NASA and across industry, academia, and international partners. The strategic analysis cycle informs architecture decisions by identifying technology gaps and needed capabilities. Each analysis cycle culminates in an annual Architecture Concept Review—a review that brings together NASA leadership to refine the existing architecture and strategies.

After the Architecture Concept Review, the SAO, in coordination with those involved in the review, releases an updated Architecture Definition Document. NASA released the initial Moon-to-Mars Architecture Definition Document in April 2023, and an updated version in January 2024.[13] The primary purpose of the document is to map high-level objectives to specific functions for programs and projects. NASA plans for future revisions to continue to document the mapping of objectives for lunar and Mars missions to existing and new flight programs, projects, and systems.

Gateway Program's Cost and Schedule Analysis Update Will Help Inform Artemis IV Launch Date Feasibility

The Gateway program plans to update its JCL analysis, in accordance with NASA policy, for its critical design-informed synchronization review that is currently scheduled for September 2024. This cost and schedule analysis will help officials assess the feasibility of the planned September 2028 Artemis IV mission date. To support this mission, the initial capability must launch 3 months before its December 2027 schedule baseline. As a result, NASA officials plan to set an accelerated date to drive contractor performance and create schedule margin.

The Gateway Program Plans to Update Its Cost and Schedule Analysis

The Gateway program plans to update the JCL analysis for the initial capability at its critical design-informed synchronization review, which is planned for September 2024. This review helps the program determine whether the Gateway's overall design performs as expected and is stable enough to support proceeding with the final design and fabrication. The program plans to hold this review after both the HALO and PPE projects have completed critical design review but prior to them completing integration and test at the project level. The updated JCL will incorporate new risks and assess the effects of cost and schedule on the baselines since the program last conducted the JCL. NASA's policy for management of space flight programs and projects

[12]See appendix II for more details on this process, including for more information about NASA's annual strategic analysis cycles and architecture concept reviews.

[13]NASA, Exploration Systems Development Mission Directorate*, Moon-to-Mars Architecture Definition Document* (ESDMD-001), NASA/TP – 20230002706 (Washington, D.C.: April 2023); Exploration Systems Development Mission Directorate, *2023 Moon to Mars Architecture Definition Document (ESDMD-001) Revision A,* NASA/TP-20230017458 (Washington, D.C.: January 2024).

requires projects with a life-cycle cost estimate of over $1 billion, such as the PPE and HALO projects, to update the JCL analysis at critical design review.[14] The policy also requires the program to communicate the updated analysis results to agency senior leaders.

An updated JCL analysis would reflect the Gateway program's current costs, schedule, and risks. Since the program's KDP I review, the HALO and PPE projects have been revising their schedules to accommodate prior milestone delays and a large contract modification, respectively. They also plan to finalize additional contract modifications, although PPE and HALO project officials said they will not know the effects on cost and schedule until the modifications are finalized in mid- to late-2024.

In addition, the updated JCL would reflect the program's dynamic risk posture. For example, in the 2 months between when the program completed its JCL analysis in March 2023 and the program's standing review board review in May 2023, 16 risks changed.[15] The board recommended integrating these changes into the program's JCL, and the program incorporated most of them.

We found that since the program finalized its JCL analysis in May 2023, with the recommended adjustments from its standing review board, the program and its projects have mitigated some risks. However, other risks have grown worse and new ones have emerged. For example:

- The HALO project took steps to mitigate a risk related to the HALO's ability to reduce its heat and control humidity inside the module. The review board was concerned about the HALO's heat management capability at the KDP I review, but the project has since determined a mitigation path that lowered the likelihood that this risk would occur. To help lower the HALO's temperature, the project plans to add software that will turn off non-critical equipment and reduce the module's heat when needed at specific times.
- A program-wide risk concerning the Gateway's communication network has worsened and resulted in new risks emerging, including related risks for Gateway's projects. The network facilitates communication throughout the Gateway. The program discovered several defects on a network chip—which affects multiple Gateway components, including the HALO's flight computer and power distribution system—during testing that could affect the network's functionality, reliability, and performance. For example, these defects could lead the flight computers to unexpectedly restart. If the network is not functioning properly, it could result in loss of control of the Gateway. Program officials are also concerned that they might identify more defects with the communication network, based on the number found already.

  To address this risk, the program formed a study team in October 2023 to determine the root cause of these defects, estimate the likelihood of discovering new defects, and recommend how to address them with minimal schedule delays. Program officials said they are working with the hardware contractor to ensure they can incorporate chip updates into the network while the Gateway is on orbit. Officials said they will not know the exact effects on schedule until the program's study team completes its findings in fall 2024.

In addition, by the planned September 2024 synchronization review, the projects will have more information about the timing of key hardware deliveries that affect their integration and test schedules. For example, after

[14]At critical design review, programs and projects assess whether they are still on track to meet their cost and schedule baselines.

[15]The standing review board is a group of independent reviewers who evaluate the program's technical and programmatic approach, progress, and risk posture.

the Gateway program conducted its JCL for the KDP I review, the SEP project delayed delivery of three advanced solar electric propulsion flight thrusters to the PPE project for integration. The SEP project, which is managing the assembly of these flight thrusters for the PPE, redesigned its thruster harnesses at the PPE project's direction to fix compatibility issues with a heritage spacecraft component.[16] As of April 2024, the SEP project estimated about a 10-month delay, due to these PPE project-driven changes, to delivering the flight thrusters to the PPE project. However, project officials said they are working with the contractor to streamline their schedule to meet the date by which the PPE project needs the flight thrusters.

The updated JCL analysis to support the September 2024 critical design-informed synchronization review presents program managers with the opportunity to decide whether they need to add more time for uncertainty in their schedules for integration and test activities. Uncertainty accounts for situations in which the program is unable to accurately predict the outcome of a future event. As part of the KDP I review for Gateway, the program's standing review board noted that the program should include more time in its schedule for the PPE's assembly and integration and for integrating the PPE and the HALO together. Further, the program's planned JCL update will help decision-makers determine whether the program has adequate cost and schedule reserves as the HALO and PPE projects enter integration and test, the riskiest development phase.

Updating the Gateway program's JCL analysis will ultimately help NASA determine the feasibility of its September 2028 Artemis IV mission date. M2M program officials also said they are considering conducting a schedule risk analysis for the Artemis IV mission.[17] The program's updated JCL analysis is expected to provide key information for this analysis, such as the current likelihood of activity durations, risks, and opportunities related to the Gateway program.

Gateway Program Is Targeting an Accelerated Launch Date to Align with Planned Artemis IV Mission Date

The Gateway program's schedule baseline does not align with the September 2028 Artemis IV mission date, but the program has a plan to support the mission. There are three key launch readiness dates that NASA is tracking:

- **December 2027 baseline launch readiness date.** This is the program's schedule baseline for the initial capability. This date is 3 months later than needed to support the planned Artemis IV mission date.
- **September 2027 need launch readiness date.** To support the planned September 2028 Artemis IV mission date, program officials said NASA will need to launch the PPE and HALO at least 12 months before the Artemis IV mission, or by September 2027. This is to allow time for the Gateway's initial capability to transit to near rectilinear halo orbit, and for the program to ensure all systems work post-launch and check the orbit's stability before vehicles dock with the HALO. The Gateway program's 2023 JCL results showed that the probability of launching the PPE and HALO in September 2027 is about 50 percent at a slightly lower funding level than the program's cost baseline. Gateway program officials also

[16]Harnesses are the groupings of wire or cable that transmit signals and electrical power.

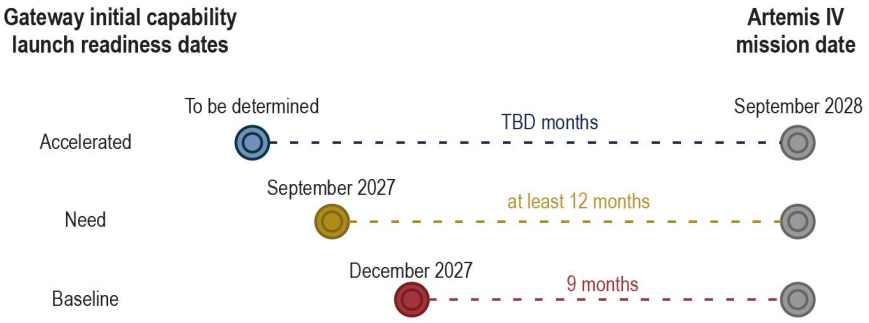
[17]A schedule risk analysis uses statistical techniques to predict the likelihood of a program's completion date, or in this case, the baseline launch readiness date. A JCL analysis uses statistical techniques to predict the likelihood of a program meeting its cost and schedule targets, or in this case, the cost baseline and baseline launch readiness date.

noted that they continue to mature their performance models and mission operations plans, and they could need an additional 2 to 4 months for transit and to check the PPE and HALO systems in orbit.

- **To be determined accelerated launch readiness date**. Gateway program officials said they recognize the baseline launch readiness date is 3 months after the PPE and HALO need to launch to support the Artemis IV mission. As a result, program officials said they plan to work to an accelerated date that is earlier than both the need and baseline launch readiness dates. In May 2024, program officials said they anticipated determining the accelerated launch readiness date in summer 2024 after receiving input from others within NASA and international partners.

Without the Gateway's initial capability, the Artemis IV mission cannot proceed as NASA currently envisions. See figure 5 for a comparison of the Gateway initial capability launch readiness dates and the Artemis IV mission date.

Figure 5: Gateway Program Launch Date Options for Artemis IV Mission (as of May 2024)



Source: GAO analysis of NASA documentation. | GAO-24-106878

Prior to approving the cost and schedule baseline for the Gateway initial capability, NASA reassessed the feasibility of the Artemis II, III, and IV mission dates. After conducting this assessment, M2M program officials said they took a similar approach with setting baselines for two other Artemis programs. M2M program officials said these programs are all working to dates earlier than their schedule baselines.

An M2M program official said they directed the Gateway and other programs to work to launch readiness dates earlier than their baseline schedules to ensure NASA meets its commitments with Congress and the Office of Management and Budget. The official said programs work with the M2M program, other NASA offices, and their contractors to determine an accelerated but feasible schedule. A feasible schedule keeps contractors working to the earliest date possible without adding risk by asking them to work to an overly optimistic schedule. According to the official, working to an accelerated date helps programs drive contractor performance, create schedule margin, and reduce the risk to the baseline launch readiness date.[18] Gateway program officials said completing work on firm-fixed-price contracts as soon as possible is also in the contractors' best interest as they assume financial responsibility of any additional costs caused by delays.

Given the changes to the PPE and HALO project schedules, the program's dynamic risk posture, and the fact that the initial capability baseline is later than the need date for the Artemis IV mission, it is important that the Gateway program execute its plan to update the JCL analysis at its next synchronization review. As discussed

[18]Margin, or schedule reserve, accounts for known risks and uncertainty in the schedule.

above, the program's planned JCL update in September 2024 will incorporate changes to risks, schedules, and costs since the last JCL and help assess whether the program can support the Artemis IV mission date.

Gateway Program Made Some Progress, but Has Significant Technical Challenges to Overcome Before the Artemis IV Mission

The Gateway program's three projects—PPE, HALO, and DSL—made varying degrees of progress in 2023 and early 2024. While later than initially planned, the PPE and HALO projects entered the final design and fabrication phase and completed their critical design reviews.[19]

The PPE and HALO projects also completed some key tasks that we previously raised as challenges.[20] For example, the PPE project reduced some risk related to its technology readiness by maturing the high-power SEP thrusters. NASA plans to demonstrate the use of these thrusters in deep space on the PPE. In July 2023, the SEP project completed acceptance testing on the first of two qualification model thrusters to mature the technology. This testing included limited vibration, thermal-cycling, and performance testing on the thruster. Similarly, the HALO project completed fabrication of its primary structure. Project officials said they began conducting a key risk mitigation test on the primary structure in May 2024 and plan to complete the test in late June 2024. The goal of the test is to ensure that the structure can withstand the force required to be launched into and operate in space after having to make several welding repairs.

The DSL project progressed into the concept and technology development phase. It is not as far along in its acquisition life cycle as the PPE and HALO projects because the project authorized the start of work on its contract for the design and development of its first logistics vehicle later than planned. NASA awarded SpaceX a contract in March 2020 to develop logistics vehicles to support Artemis missions. However, NASA did not modify its contract with SpaceX to proceed with work to develop and build its first logistics vehicle until November 2023. NASA officials previously told us they delayed ordering the work due to funding constraints and other NASA priorities.[21]

While the PPE and HALO projects made progress toward finalizing their designs, our review of program documentation found that they have several significant technical and design-related challenges to overcome. These include maturing outstanding critical technologies and designs, controlling the Gateway in lunar orbit, and reducing the mass of the combined PPE and HALO for launch and transit to lunar orbit. In addition, M2M-level risks and pending decisions may also affect the Gateway program and its plans.

Delays to maturing technologies and designs. While proceeding through preliminary and critical design reviews, the PPE and HALO projects did not always meet our best practices for technology readiness and

[19]When NASA established a preliminary cost and schedule estimate for the Gateway initial capability, the program estimated that the HALO project would complete its critical design review in March 2022 and the PPE project in May 2022. The HALO project delayed its review to allow for time to address design issues and to further mature key subsystems. The PPE project delayed its review to incorporate a high volume of requirements changes into its design.

[20]GAO, *NASA: Assessments of Major Projects,* GAO-23-106021 (Washington, D.C.: May 31, 2023).

[21]GAO, *NASA: Assessments of Major Projects*, GAO-22-105212 (Washington, D.C.: June 23, 2022).

design stability.[22] Meeting these best practices can help projects to minimize risk in future phases of development, including limiting future design changes that could result in cost growth and schedule delays. See table 2 for a description of our best practices, the extent to which the projects met them, and project plans to mature outstanding technologies and designs.

Table 2: Extent to Which PPE and HALO Projects Met GAO Best Practices for Technology Readiness and Design Stability as of April 2024

Project	GAO best practice to mature technologies to technology readiness level 6 by preliminary design review[a]	GAO best practice to release 90 percent of design drawings by critical design review[b]
Power and Propulsion Element (PPE)	The PPE project did not mature any of its nine critical technologies at its preliminary design review in 2021. Since then, the project matured seven of the technologies. The two remaining technologies relate to how the PPE operates its solar electric propulsion thrusters and provides connectivity between the PPE, Gateway, and visiting vehicles. According to project officials, the remaining two technologies will not be mature until after the critical design review, which the project held in March 2024. Project officials said that the project's prime contractor has a different view on the timing of maturing technologies. The officials said they do not view either of the remaining two technologies as a major risk.	The PPE project reported that it released over 90 percent of its design drawings at its critical design review in March 2024. However, when a project has immature technologies, it increases the risk of project officials approving a design that is less likely to remain stable.
Habitation and Logistics Outpost (HALO)	The HALO project matured all of its critical technologies by its preliminary design review in 2021.	The HALO project reported that it released 41 percent of its design drawings at its critical design review in 2023. Project officials attributed the low drawing counts primarily to the lower level of maturity of the HALO's environment control and life support subsystem. HALO project officials said that they could mature this subsystem's design later because it sits on a rack or sled device and the contractor can install the entire subsystem at once. As a result, they have primarily focused on maturing the design of the interfaces between the subsystem and the HALO module leading up to a review later in 2024, specifically on this subsystem. Officials said they plan to release additional drawings by the end of 2024, which would get them closer to 90 percent released.

Source: GAO analysis of Gateway program documentation and interviews with officials. | GAO-24-106878

[a]GAO considers a technology mature for space systems when it reaches a technology readiness level 6, which includes demonstrating a representative prototype of the technology in a relevant environment that simulates the harsh conditions of space. NASA's systems engineering policies align with GAO's technology maturity best practice.

[b]GAO considers engineering drawings a good measure of the demonstrated stability of a product's design because the drawings represent the language used by engineers to communicate to the manufacturers the details of a new product design—what it looks like, how its components interface, how it functions, how to build it, and what critical materials and processes are required to fabricate and test it. Once the contractor finalizes the design of a product, the drawing is releasable.

Gateway stack controllability. The Gateway program is tracking a risk related to the PPE's ability to keep the Gateway integrated stack in the right orbit and pointing in the right direction when large, heavier vehicles are docked with the Gateway. The integrated stack includes Gateway components like the HALO and other

[22]GAO-04-386SP; and GAO-02-701.

docked spacecraft like lunar landers. Losing precise control of the Gateway integrated stack could result in degradation of performance. For example, if the Gateway is not pointed in the right direction, it could affect communications or the ability for visiting vehicles to successfully dock with the Gateway.

Gateway program officials told us their analysis indicates that there are certain operational scenarios, such as when the lunar lander Starship docks with the Gateway, in which the PPE may not be able to maintain control of the integrated stack. Gateway program officials said that the PPE is meeting the performance requirements for stack controllability that NASA set for it. However, those requirements do not account for the mass of some visiting vehicles that plan to dock with the Gateway. As a result, when these larger than anticipated visiting vehicles dock with the Gateway, the integrated stack may be outside of these controllability parameters (e.g., larger in volume or mass). For example, program officials estimate that the mass of the lunar lander Starship is approximately 18 times greater than the value NASA used to develop the PPE's controllability parameters.

Gateway program officials are conducting additional analyses and studying two main ways to mitigate this risk prior to the program's September 2024 critical design-informed synchronization review. The first way is to have visiting vehicles, such as a logistics vehicle, share some control with the PPE when docked with the Gateway by firing their thrusters for a period, or to require docked visiting vehicle with a mass greater than these original parameters, such as Starship, to control the integrated stack when docked with the Gateway. The second way is making changes to the control algorithms for the PPE to improve control throughout the entire docking process.[23] This includes improving how the program selects different thrusters to fire and to optimize fuel use based on the visiting vehicle that is docking with the Gateway. If neither of these options mitigate the risk, then NASA plans to either change the PPE's requirements or add requirements for visiting vehicles. According to NASA's system engineering guidance, late requirements and design changes can lead to cost growth and schedule delays.[24]

Comanifested vehicle (CMV) mass. The HALO and PPE projects are both exceeding their mass allocations as part of the CMV. Prior to launch, NASA plans to integrate the PPE and the HALO together on the ground, which creates the CMV. NASA considers mass a leading indicator—a measure that predicts future performance—and a key measure of design maturity and stability.[25] The Gateway program monitors the overall CMV and each project's mass estimates compared to their allocations to the CMV. If the projects cannot reduce mass to within their allocations, it could affect the CMV's ability to reach the correct lunar orbit. In addition, if the projects need to implement late design changes to reduce their mass, it could result in cost growth or schedule delays. As noted above, NASA's systems engineering guidance indicates that, in general, the later projects make design changes, the larger their negative effect on cost and schedule. The projects have options other than making design changes to reduce mass. These include (1) removing components and reducing capabilities, which would affect performance, (2) carrying components up on a logistics vehicle and having crew install them on-orbit, or (3) narrowing launch windows to those that use less fuel for transit.

The HALO's mass is the primary driver of the CMV exceeding its mass allocation. The HALO's mass increased last year as the project matured its design for internal structures and started receiving more accurate estimates

[23]An algorithm is a set of rules that a computer follows to compute an outcome.

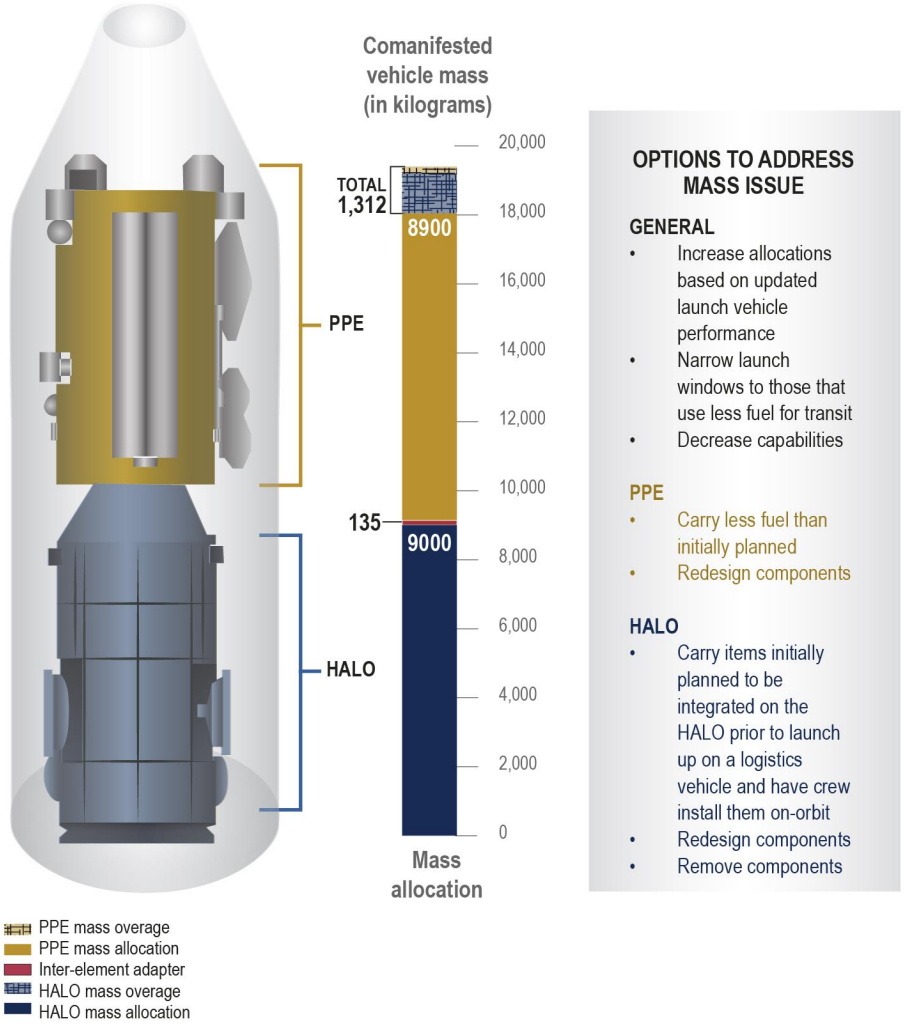
[24]NASA, *NASA Systems Engineering Handbook,* NASA/SP-2016-6105 Rev 2 (Washington, D.C.: 2016).

[25]NASA, *NASA Common Leading Indicators Detailed Reference Guide* (January 2021). Mass is a measurement of how much matter is in an object. It is related to an object's weight, which is mathematically equal to mass multiplied by acceleration due to gravity. When an object goes into space, its weight changes with gravity, but its mass stays the same.

of hardware weights or the hardware itself. In addition, project officials said the HALO's mass increased by 602 kilograms because the project's contractor used an incorrect estimation method to calculate wire harness mass.

See figure 6 for the CMV mass, how much over the mass allocations each project is, and the program's options to address the mass issue.

Figure 6: Comanifested Vehicle Mass and Options to Address Habitation and Logistics Outpost (HALO) and Power and Propulsion Element (PPE) Mass Growth Over Allocations



Source: Gateway program documentation and interviews with program and project officials (data); GAO illustration based on NASA image. | GAO-24-106878

Accessible Data for Figure 6: Comanifested Vehicle Mass and Options to Address Habitation and Logistics Outpost (HALO) and Power and Propulsion Element (PPE) Mass Growth Over Allocations

	Comanifested vehicle mass (in kilograms)
Halo mass allocation	9000
Inter-element adapter	135
PPE mass allocation	8900
Halo mass overage	1312
PPE mass overage	1312

Source: Gateway program documentation and interviews with program and project officials (data); GAO illustration based on NASA image. I GAO-24-106878

NASA's system engineering policy states that one of the criteria for projects to successfully complete the critical design review is to be within their mass allocation with some margin available.[26] The PPE and HALO projects did not meet this criterion at their reviews. Subsequently, the HALO project and its contractor began to identify solutions to the mass overage, which will inform a HALO project mass reduction plan. Gateway program officials said that if the projects are not meeting their mass allocation by the program-level critical design-informed synchronization review (scheduled for September 2024), they expect that the projects would submit waivers, or requests to deviate from the requirements, for review at that time.

Gateway program officials said that decisions on how to reduce the mass of the CMV are based on a variety of factors that affect the Gateway's overall mission design and performance. These factors include the predicted mass of HALO and PPE components, power needs, propellant on board, launch vehicle performance, launch windows and trajectories, and the amount of time the CMV needs to transit to lunar orbit. Part of making mass decisions also includes determining how much mass to allocate for HALO components on the logistics vehicle for the Artemis IV mission.

Gateway program officials said they will make decisions on what the first logistics vehicle will carry as they get closer to the 2028 mission. The HALO project identified over 300 kilograms of components to potentially deliver via a logistics vehicle to the Gateway for the crew to install on-orbit. However, the Gateway program will have to balance a decision about whether to carry HALO components on the logistics vehicle with other mission needs. For example, the International Habitat, which the European Space Agency is contributing, is also exceeding its launch mass and may need the logistics vehicle to carry up items to reduce its mass. In addition, the logistics vehicle will also need to carry up cargo; consumables, such as water and food that the crew will need for the mission; and other items.

The Gateway program oversees the efforts to reduce the CMV mass, including determining how to reduce it and what the logistics vehicle will carry. Program officials said they have verbally discussed an approach to reducing mass with the projects, but the program office has not yet documented an overall plan to manage the PPE and HALO mass reduction efforts. *Standards for Internal Control in the Federal Government* states that management should document its internal controls—or processes management uses to help an entity achieve its objectives—and communicate quality information to all levels of the entity.[27] NASA's program management and systems engineering policy and implementing guidance do not require programs to develop such a plan, but most programs are only responsible for the mass of a single project or system. The Gateway program is

[26]NASA, *NASA Systems Engineering Processes and Requirements,* Procedural Requirements 7123.1C (Feb. 14, 2020).

[27]GAO-14-704G.

integrating across multiple projects and systems. Therefore, it is important that the Gateway program communicates its overall mass management plan with the PPE, HALO, and DSL projects.

The Gateway program and its projects have many factors to consider when making decisions about how to reduce the CMV mass. Documenting the Gateway program's overall mass management plan and communicating it internally within the program would help ensure that all involved parties agree on how to overcome the CMV mass challenge. This would include ensuring that at the September 2024 critical design-informed synchronization review (1) the HALO project's specific mass reduction plan aligns with the program's overall mass management plan, and (2) all parties are aware of priorities for making key trade off decisions, including what the logistics vehicle will carry for the Artemis IV mission. Without documenting the mass management plan, the program risks the projects making individual decisions to reduce mass without considering how those decisions affect other projects and the overall mission design.

M2M-level risks and pending decisions. Several M2M-level risks and pending decisions could affect the Gateway program. For example:

- The M2M and Gateway programs are tracking risks related to mission operations that affect multiple programs. For example, the Gateway program will need to carefully manage where the visiting vehicles—such as a logistics vehicle, Orion, or a lunar lander—are docked and pointed throughout the mission. The Gateway and the visiting vehicles all have thermal, power, and communication needs, which require them to point in a certain direction at different times depending on lighting from the sun. If NASA cannot identify solutions to meet all visiting vehicle needs, it risks degraded performance for some vehicles, such as not generating enough power from solar arrays, or in a worst-case scenario, loss of mission. To mitigate this risk, visiting vehicles might have to undock with the Gateway and later redock over the course of the mission. For example, Gateway program officials said that after the crew integrates the International Habitat with the rest of the Gateway, they might have to move Orion and redock it in another position to ensure that it is facing in a direction to meet its thermal needs. The program office is conducting additional analysis in spring 2024 to determine the various vehicle needs.
- In addition, the M2M program has not yet determined how many revolutions in orbit the crew will spend on the Gateway. The higher the number of revolutions, the more consumables required on the Gateway for crew, which affects mass. As noted above, the Gateway program will have to make decisions about what it brings up on its logistics vehicle. The more consumables needed, the less mass that is available for other items.
- M2M program officials said they are continually assessing Artemis mission profiles and concepts of operations for crew safety.[28] As part of this assessment, M2M program officials said they consider scenarios on how they might change a mission profile if one of the programs is not ready on time. If NASA decides to make changes to its mission profiles, it could result in changes to planned time frames or the anticipated concept of operations for the Gateway program. As of April 2024, M2M program officials said they did not plan to make any changes.

It is important that the Gateway program ensures that the program and the PPE and HALO projects complete their efforts to mature technologies, improve design stability, and mitigate significant technical challenges and risks as the Gateway program moves toward its critical design-informed synchronization review in September

[28]A mission profile is a brief description of the mission and its objectives. The concepts of operations are the more detailed plans for how the agency plans to use systems to achieve a mission's objective. For example, see the Artemis IV mission concept of operations depicted in figure 2.

2024. This will help the program assess whether the overall Gateway design performs as expected. As part of the updated JCL at this review, the program will also be able to account for how these efforts affect the program's risk posture. For example, if the program documents its mass management plan and identifies ways to reduce the CMV mass without making design changes, it may reduce the associated consequences on cost, schedule, and performance before the PPE and HALO projects enter the system integration and test phase. Conversely, if program officials determine that they must make design changes to reduce mass, they can account for any associated cost growth or schedule delays in the JCL analysis.

NASA Plans Annual Reviews to Determine Roles for the Gateway in Future Mars Missions

NASA has held two Architecture Concept Reviews to map its high-level M2M exploration goals to the elements that are needed to achieve them. These two reviews largely focused on establishing the architecture review process and aligning existing systems, such as the Gateway, to the architecture. NASA plans to hold future reviews on an annual basis. Thus far, NASA has assigned several functions to the Gateway program that align to goals of the initial Artemis missions, like returning humans to the moon. NASA plans to use future reviews to determine if it needs to add capabilities to the Gateway to support the later segments, which will build on these early lunar explorations and eventually send a crew to Mars.

NASA's Initial Architecture Concept Reviews Focused on Early Lunar Missions

The Strategy and Architecture Office (SAO) plans to hold reviews in the November time frame each year to map NASA's high-level M2M exploration goals to the elements that are needed to achieve them. NASA held its first Architecture Concept Review in January and February 2023 and its second in November 2023. According to officials, the November time frame allows the Architecture Concept Review to inform the budget request for the following year. To establish this desired yearly cadence, NASA shortened the length of the first two review cycles. NASA plans for future cycles to last a full 12 months. In upcoming cycles, NASA plans to make numerous key decisions related to Mars missions in the areas of surface systems; entry, descent, landing, and ascent systems; transportation; and crew support.

NASA organized the M2M architecture into four segments that increase in complexity and mission scope over time:

- **Human Lunar Return:** the initial capabilities, systems, and operations necessary to re-establish human presence on and around the moon.
- **Foundational Exploration:** the expansion of lunar capabilities, systems, and operations supporting complex orbital and surface missions to conduct science and Mars precursor missions.
- **Sustained Lunar Evolution:** the enabling capabilities, systems, and operations to support science, economic opportunity, and a steady human presence on and around the moon.
- **Humans to Mars:** the initial capabilities, systems, and operations necessary to establish human presence and enable science and continued exploration on Mars.

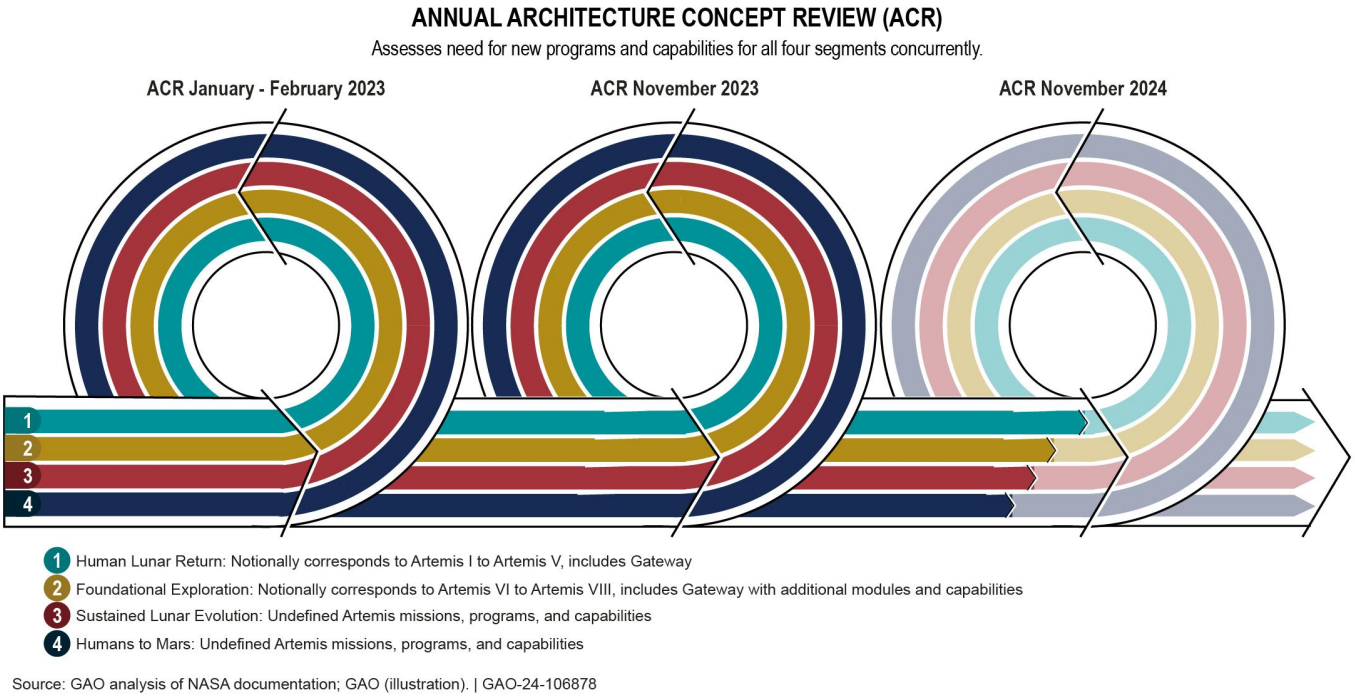
The segmented approach allows NASA to incrementally develop and deploy elements as needed. It also allows NASA to break the architecture down into manageable pieces to prioritize its analysis work and

coordinate with commercial, academic, and international partners. According to SAO officials, the agency is building out the segments concurrently, as mission and segment operations may overlap. Therefore, it is not necessary to complete one segment before operations in the next segment begin. Officials said this approach allows them to prioritize areas that have a time sensitivity associated with them across all the segments.

Due to the abbreviated nature of the first two review cycles, those reviews largely focused on establishing the process and aligning existing systems to the architecture. In particular, the first review cycle and its associated products focused on the first segment of the architecture, Human Lunar Return. That review cycle included coordination with each of NASA's mission directorates. The second review cycle expanded on the first. It focused on refining and adding detail to the Human Lunar Return and Foundational Exploration segments, added elements that are further along in development, and developed strategies for making decisions about the eventual first crewed missions to Mars.

Within the four segments, NASA's architecture reviews have made the most progress in the Human Lunar Return segment in terms of mapping high-level objectives to more specific functions and allocating those functions to elements. Elements are flight programs, projects, and systems, such as the Gateway. NASA has also made progress in the Foundational Exploration segment, but to a lesser extent. NASA has not completed mapping objectives to specific elements for the Sustained Lunar Evolution. However, it completed some examples of notional mapping, such as for future habitation and transportation systems. NASA has not completed mapping objectives to elements for the Humans to Mars segment. See figure 7 for the four segments and the status of developing these segments as of January 2024.

Figure 7: Moon to Mars Architecture Segments as of January 2024



Source: GAO analysis of NASA documentation; GAO (illustration). | GAO-24-106878

Note: According to Strategy and Architecture Office officials, the specific flight manifests, sequences, and specific mission content and design are notional and are subject to change due to factors such as budget, schedule, and other pressures that are beyond the scope of the architecture team.

As of the second architecture concept review in November 2023, NASA determined roles for the Gateway, as well as other existing Artemis systems, for the first two architecture segments—Human Lunar Return and Foundational Exploration. However, the agency had not yet determined roles for existing Artemis systems for the two later architecture segments—Sustained Lunar Evolution or Humans to Mars. For example:

- In the Human Lunar Return architecture segment, NASA determined that the Gateway will demonstrate the ability to conduct crewed lunar surface missions from cislunar space.[29] It will also provide capability for the physical assembly of spacecraft elements and crew habitation in cislunar space, among other contributions.
- In the Foundational Exploration architecture segment, the Gateway, including its international partner contributions, will provide a pressurized habitable environment in cislunar space for durations of months to years. The Gateway will also allow NASA to remotely operate the habitation system between crewed missions on the lunar surface and provide the capability to restore and stabilize the habitable environment.

Future Reviews Will Determine How Gateway Will Support Later Missions, Including to Mars

While NASA has not formally determined how the Gateway program will support the Sustained Lunar Exploration or Humans to Mars segments, the agency considers the Gateway a critical element of its M2M architecture. The SAO office is analyzing several potential uses of the Gateway as a proving ground for lunar surface activities and Mars development. For example:

- **Operating an unattended system in deep space:** The Gateway will spend most of its life uncrewed, for durations up to 3 years at a time, which is likely analogous for future Mars class systems.
- **Long-term demonstration of a Mars transit habitat:** The Gateway will provide the ability to stage long-duration microgravity systems in deep space or near-deep space equivalent environmental conditions and enable Mars-like analog missions closer to Earth.
- **Crew transitions between micro-gravity and partial gravity:** The Gateway's location in cislunar space will further NASA's understanding of crew transitions between microgravity and partial gravity environments to help NASA prepare for Mars exploration.
- **Orbit-to-surface split crew operations:** The Gateway will enable NASA to analyze conducting missions and station operations with some crew remaining on the Gateway while others descend to the lunar surface.
- **Observations, science, and technology demonstrations in lunar orbit:** The Gateway will enable progress toward Earth independence through applied science and investigations in areas such as atmospheric weather, space weather, and dust.

The SAO laid out several key decisions that it needs to make in upcoming review cycles and has started studies to inform those decisions. For example, the SAO plans to determine how it will transport crew to Mars, which could involve the Gateway. NASA plans to design a transit system to transport the crew; surface systems; and entry, descent, and landing systems to deep space locations, including Mars, and to return crew back to Earth. NASA is considering the Gateway as an aggregation point—a location where NASA could

[29]Cislunar space is the volume of space around the moon featuring multiple possible stable staging orbits for future deep space missions.

physically assemble vehicles for missions in deep space—including to Mars. NASA officials told us that aggregating the Mars transit vehicle at the Gateway is likely the preferred option because its location in near rectilinear halo orbit is an advantage.[30]

SAO officials told us it would likely take several annual review cycles to fully determine the Gateway's role in later Mars missions. Thus, it could be several years before NASA fully understands the Gateway's role and contributions to these missions. Even if NASA identifies new capabilities for the Gateway, SAO and Gateway program officials said that they expect that they would be minor—such as software updates or moving the Gateway between orbits—and would likely not affect the initial capability. The January 2024 revised Architecture Definition Document notes that NASA should limit modifications to programs already in development. In the case of the Gateway initial capability, the PPE and HALO projects were in development for several years before the establishment of the Moon to Mars strategy. Design changes beyond this point would be costly to implement and could result in reduced capabilities. In addition, and as noted above, the projects are addressing significant mass concerns and other challenges, which could limit NASA's ability to add new capabilities to the Gateway's initial capability.

While significant design changes to the Gateway's initial capability are not feasible, NASA may be able to add capability to the Gateway over time. NASA designed the Gateway for compatibility with the International Deep Space Interoperability Standards, which enable industry and international entities to independently develop compatible systems for deep space exploration.[31] Officials said the Gateway also provides a platform and docking ports for scalability to accommodate additions, such as a new module. As NASA continues to build out its architecture for later lunar and Mars missions, SAO and Gateway officials noted that the program would provide input throughout the architecture concept review process on the Gateway's capabilities and constraints.

In our discussions with Gateway program officials, they noted two constraints that would affect the Gateway's ability to support Mars missions:

Stack controllability. According to Gateway program officials, stack controllability is the biggest constraint that the SAO and the Gateway program have discussed for future missions. As previously noted, if NASA decides to allow large, heavier visiting vehicles to dock with the Gateway, it affects the PPE's ability to control the stack. The program will need to reconsider the Gateway's mass capability calculations, including the size of the additional vehicle and its center of gravity, as NASA makes these decisions. In the case of a future Mars transit vehicle, officials said there are no designs currently mature enough for the Gateway program to determine how it will handle stack controllability. Officials said they would need to make adaptations on a case-by-case basis.

Life of the Gateway. The Gateway's planned on-orbit life of 15 years could also limit its use, depending on the timing of crewed Mars missions. Gateway program officials said they expect the Gateway to exceed its mission

[30]According to NASA, near rectilinear halo orbit is the optimal orbit to support the goals of the Artemis campaign because it provides low-cost, long-term stability, an environment achievable for vehicle designs, and accessibility for transportation elements. It also provides a favorable vantage point for Earth, sun, and deep space observations in a magnetically shielded environment, depending on the phase of the moon's orbit.

[31]NASA and the International Space Station partner agencies collaborated to develop the *International Deep Space Interoperability Standards*. The standards include nine discipline areas: avionics, communications, docking, environmental control and life support systems, power, rendezvous, robotics, thermal, and software. The Gateway is the first program to implement the standards.

life as other systems have done. For example, NASA also designed the International Space Station for a 15-year mission life, which it has now exceeded by over 11 years. NASA expects to continue International Space Station operations until 2030. The Gateway, however, will operate in a different environment. It will be in cislunar space, where it will be exposed to higher levels of radiation than the International Space Station, which is in low Earth orbit. In addition, the Gateway will spend significant periods of time uncrewed between Artemis missions, while the International Space Station has been continuously crewed. The Gateway is planned to rely on numerous autonomous systems, such as robotics systems, to operate and maintain it between crewed missions and to prepare for the arrival of the next crew. However, to the extent that these systems fail or that the Gateway needs more maintenance than the autonomous systems can provide, the Gateway could be adversely affected. These factors could limit an extended on-orbit life. Further, independent studies requested by NASA show that the agency has explored launching Mars missions in 2039, though the studies noted several potential challenges to achieving this date. The Gateway program is currently working to launch its initial capability in 2027; thus, the Gateway could have exceeded its planned 15-year on-orbit life as early as 2042 when crewed missions to Mars are potentially just beginning.

NASA's ultimate goal with its lunar efforts is to prepare for crewed missions to Mars. The agency views the Gateway as a key asset in its efforts to create a sustainable lunar presence and test out technologies and concepts of operations for Mars. While the agency is past the point that it can make significant design changes to the Gateway, it may be able to add capability via software updates or by adding new modules. NASA plans to use its annual review cycles to identify ways it can more fully leverage the potential contributions of the Gateway, while balancing the Gateway's limitations, to inform its eventual plans for crewed Mars missions.

Conclusions

The Gateway program plans to launch the PPE and HALO together in 2027, in about 3 years. Between now and then, the projects will go through the riskiest phase of development—integration and test. Before they do so, the Gateway program will have an opportunity to assess its mission design and schedule at its planned September 2024 critical design-informed synchronization review. Addressing known risks and understanding their effect on the program is an important part of this process. The PPE and HALO projects have several significant challenges to overcome and risks to mitigate as they enter the integration and test phase, including reducing their mass to within their allocations. The program and its projects have plans to address some of these challenges prior to the review, such as conducting analyses related to stack controllability. However, the PPE and HALO projects are at the point where they are building hardware, and the program has not yet documented how to address their mass overages. As a result, NASA is at risk of building hardware that could need significant redesigns that would increase costs and delay schedule. Documenting a mass management plan and ensuring that all relevant parties can make timely decisions in alignment with that plan would be a key step for the program to ensure it has an executable mission design.

Recommendation for Executive Action

The NASA Administrator, in coordination with the Exploration Systems Development Mission Directorate, should ensure that the Gateway program documents its overall mass management plan and shares it with its projects ahead of the program's planned September 2024 critical design-informed synchronization review. (Recommendation 1)

Agency Comments and Our Evaluation

We provided a copy of this report to NASA for review and comment. NASA provided written comments that are reprinted in appendix III. In its response, NASA concurred with our recommendation and estimated it would take action to implement this recommendation in September 2024. NASA also provided technical comments that we incorporated 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 https://www.gao.gov.

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

William Russell
Director, Contracting and National Security Acquisitions

List of Committees

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

The Honorable Frank Lucas
Chairman
The Honorable Zoe Lofgren
Ranking Member
Committee on Science, Space, and Technology
House of Representatives

The Honorable Hal Rogers
Chairman
The Honorable Matt Cartwright
Ranking Member
Subcommittee on Commerce, Justice, Science, and Related Agencies
Committee on Appropriations
House of Representatives

Appendix I: Objectives, Scope, and Methodology

This report examined (1) the Gateway program's plans for updating its cost and schedule analysis for its initial capability, (2) the extent to which the Gateway program has made progress with the Power and Propulsion Element (PPE), Habitation and Logistics Outpost (HALO), and the first Deep Space Logistics (DSL) vehicle needed to support the Artemis IV mission in 2028 and is addressing project risks, and (3) the National Aeronautics and Space Administration's (NASA) processes for determining how it will use the Gateway to support missions beyond Artemis IV, including Mars missions. This is the latest in a series of GAO reports addressing NASA's Artemis enterprise.[1] The focus of this report is on the Gateway program and its U.S.-led development projects.

To understand the Gateway program plans to update the cost and schedule analysis for the initial capability, we reviewed the Gateway program's documentation, including key decision point (KDP) I review materials, and NASA's program and project management policy.[2] We also interviewed program officials to understand their methodology for and plans to update their joint cost and schedule confidence level (JCL) analysis and hold a KDP II review. To assess how the program's schedule, contracts, and risk posture have changed since the program conducted the JCL and might change when the program updates its JCL, we reviewed program and project documentation of top risks, program quarterly reviews, and KDP I review documentation. This included the results of the JCL and findings and recommendations from the program's independent standing review board. We also interviewed program and project officials on the KDP I review results, new risks and mitigation plans, schedule updates, and upcoming contract modifications.

In addition, to determine the extent to which the initial capability baseline and accelerated launch readiness dates support the Artemis IV mission, we reviewed the December 2023 KDP I decision memorandum that included the program's cost and schedule baselines for the initial capability, contract documentation, quarterly program reviews, and risk information. To determine the date that the Gateway program would need to launch the PPE and HALO together to support the Artemis IV mission, we assessed program documentation and interviewed HALO project and Gateway program officials on the time needed for the initial capability to transit to orbit and check the orbit's stability prior to the start of the Artemis IV mission. We refer to this date as the need launch readiness date in the report. To determine the program's ability to support the Artemis IV mission date, we compared the need launch readiness date to the baseline launch readiness date. We interviewed Gateway program and HALO and PPE project officials to discuss their plans for determining an accelerated launch readiness date. We interviewed Moon to Mars (M2M) program officials to discuss their reassessment of Artemis programs and mission dates and their program and risk management approach for the Artemis programs.

[1]GAO, *NASA Artemis Programs: Crewed Moon Landing Faces Multiple Challenges,* GAO-24-106256 (Washington, D.C.: Nov. 30, 2023); *NASA Lunar Programs: Improved Mission Guidance Needed as Artemis Complexity Grows*, GAO-22-105323 (Washington, D.C.: Sept. 8, 2022); *NASA Lunar Programs: Significant Work Remains, Underscoring Challenges to Achieving Moon Landing in 2024*, GAO-21-330 (Washington, D.C.: May 26, 2021); *NASA Human Space Exploration: Significant Investments in Future Capabilities Require Strengthened Management Oversight*, GAO-21-105 (Washington, D.C.: Dec. 15, 2020); and *NASA Lunar Programs: Opportunities Exist to Strengthen Analyses and Plans for Moon Landing*, GAO-20-68 (Washington, D.C.: Dec. 19, 2019).

[2]NASA, *NASA Space Flight Program and Project Management Requirements*, NASA Procedural Requirements 7120.5F (Aug. 3, 2021).

To determine the extent to which the Gateway program has made progress with the PPE, the HALO, and the first DSL vehicle needed to support the Artemis IV mission in 2028, and is addressing project risks, we (1) analyzed program documents, (2) determined if the projects met our best practices for technology readiness and design stability, and (3) assessed the projects' progress against NASA's policies and guidance. More specifically, we analyzed Gateway program and project documentation that contained data on the projects' accomplishments, schedules, designs, technical challenges, and risks. This included documentation and data from the Gateway program's quarterly reviews from April 2023 to February 2024, KDP I review, and the June 2023 HALO and March 2024 PPE project critical design reviews. We also analyzed documentation from the Solar Electric Propulsion (SEP) project, including monthly review slides from May 2023 to April 2024, to determine the project's progress on maturing the technology for the PPE's flight thrusters and the status of building the hardware. We compared the progress of the Gateway program and its projects against the NASA acquisition life cycle in NASA's policy for program management for space flight projects.[3]

To determine if the projects met our best practices for technology readiness and design stability, we obtained data from the PPE and HALO projects on the technology readiness levels of their critical technologies at preliminary design review and the percentage of design drawings released at critical design review through a data collection instrument. We then discussed this in interviews with project officials and compared these data against our best practices.[4] We interviewed Gateway program and PPE, HALO, DSL, and SEP project officials on the status of designing and developing hardware and software and to discuss the results of their technical reviews.

To assess the projects' progress toward mitigating technical and design risks and challenges, such as the projects exceeding their mass allocations, we compared program and project documentation of top risks and challenges and mitigation plans against NASA systems engineering policy and guidance and NASA's leading indicators reference guide.[5] We interviewed Gateway program and PPE, HALO, DSL, and SEP project officials to discuss the status of developing hardware and software, to program and project risks, and risk mitigation plans. In addition, we assessed M2M risk information and status review slides to identify any M2M level risks or decisions that might affect the Gateway program's progress. We interviewed M2M program officials to discuss those risks and decisions, as well as the Artemis IV concept of operations.

We also determined that the control environment and information and communication components of federal standards for internal control were applicable to our second objective.[6] To evaluate the control environment, we determined that the documentation of the internal control system principle was applicable. To evaluate NASA's control environment, we assessed Gateway program documentation and interviewed program officials on their plans to document key controls, including how they planned to manage mass for the comanifested vehicle. For the information and communication component, we determined the principle that management

[3]NASA, *NASA Space Flight Program and Project Management Requirements*, NASA Procedural Requirements 7120.5F (Aug. 3, 2021).

[4]GAO, *Best Practices: Using a Knowledge-Based Approach to Improve Weapon Acquisition*, GAO-04-386SP (Washington, D.C.: Jan. 1, 2004); and *Best Practices: Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes*, GAO-02-701 (Washington, D.C.: July 15, 2002).

[5]NASA, *NASA Systems Engineering Handbook,* NASA/SP-2016-6105 Rev 2 (2016) *NASA Common Leading Indicators Detailed Reference Guide* (January 2021); and *NASA Systems Engineering Processes and Requirements,* Procedural Requirements 7123.1C (Feb. 14, 2020).

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

should internally communicate quality information to achieve an entity's objectives was applicable. To evaluate this component, we assessed Gateway program documentation, including documentation of program and project updates and risk management plans, and interviewed program and project officials to determine how the program communicated risk information internally, including with its projects.

To examine NASA's processes for determining how it will use the Gateway to support missions beyond Artemis IV, including Mars missions, we reviewed documentation of NASA's architecture concept review process—the process the agency is using to map high-level M2M objectives to the specific elements that will support science and exploration goals. More specifically, we reviewed documentation from NASA's early 2023 and November 2023 architecture concept reviews and strategic analysis cycles including the Architecture Definition Document, white papers, architecture summary documents, and briefing slides. We also reviewed M2M and Gateway program documents including risk management and requirements documents.

To understand how NASA defines systems architecture and how NASA has organized itself to develop and oversee its M2M architecture, we reviewed NASA systems engineering policies and guidance; program and project management policies and guidance; and documentation of the Exploration Systems Development Mission Directorate's organizational structure. We interviewed M2M program officials to discuss updates to the agency organizational structure and how the M2M program coordinates with other offices. We interviewed Strategy and Architecture Office (SAO) officials to discuss the strategic analysis cycle and architecture concept review process, the extent to which the Gateway's role in missions beyond Artemis IV has been determined, how the office coordinates with internal and external stakeholders, and the office's plans and expectations to fully define the Gateway's role in such missions. We also interviewed Gateway program officials to discuss their participation in the architecture concept review process, ongoing trade studies, and the extent to which new requirements had been levied on the program as a result of these new processes, if at all. We also discussed NASA's potential plans to use the Gateway as an assembly point for a future Mars transportation vehicle and limitations of the Gateway with both SAO and Gateway program officials.

We conducted this performance audit from May 2023 to July 2024 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

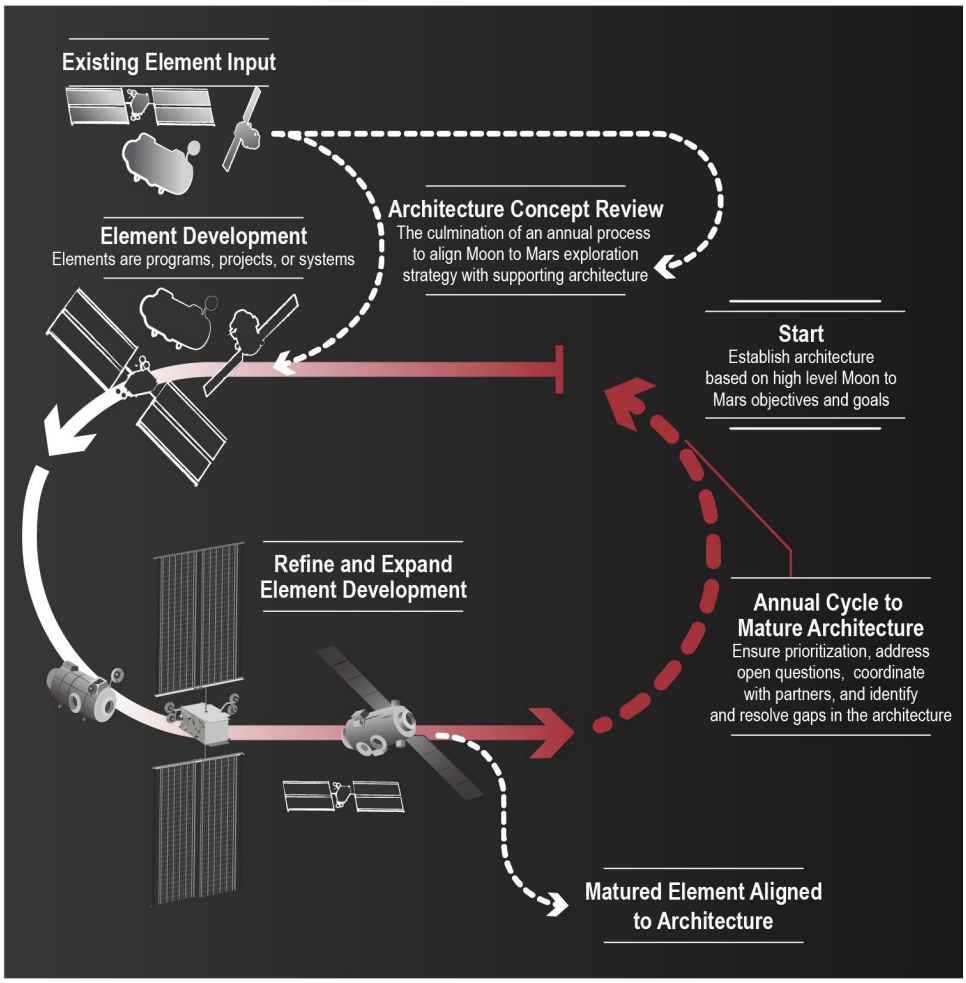
Appendix II: NASA's Annual Architecture Concept Review Process

NASA created the Architecture Concept Review process to map high-level objectives to the specific elements that will support science and exploration goals. The process centers on an annual study cycle—called the Strategic Analysis Cycle. During this analysis cycle, NASA continually updates and refines the architecture, incorporating feedback from stakeholders from within NASA and across industry, academia, and international partners. Each analysis cycle culminates in an annual Architecture Concept Review—a review that brings together NASA leadership to refine the existing architecture and strategies.

NASA's architecture concept review process is based on "architecting from the right, executing from the left."[1] The agency begins by tracing the broadest, most long-term goals that are furthest in the future on the timeline from NASA's high-level objectives and then works backward from that goal to establish the complete set of required elements. Currently, the driver for the overall architecture is planning for a human mission to Mars. Meanwhile, systems and elements are "executed from the left" in a regular development process, integrating systems as they move left to right within the architecture (see fig. 8).

[1]NASA, Exploration Systems Development Mission Directorate, *2023 Moon to Mars Architecture Definition Document (ESDMD-001) Revision A,* NASA/TP-20230017458 (Washington, D.C.: January 2024).

Figure 8: Notional Architecture Concept Review Process



Source: GAO analysis of NASA documentation; GAO (illustration). | GAO-24-106878

NASA's Architecture Definition Document states that the agency is using an applied systems engineering method to facilitate applying these principles to the architecture definition. The first part of this method is an ordered process of objectives' decomposition to complete the process of architecting from the right. In this process, NASA officials identify the characteristics and needs to assure objective satisfaction. They then trace these characteristics and needs to the functions and use cases that elements and systems must accomplish.[2] The second supporting method is establishing an architectural framework to organize, integrate, and track the allocation of functions and use cases to the executing programs. This structure is intended to enable the integration of the system-of-systems development, identify gaps in the architecture, and adjust the architecture as left-to-right execution occurs, technologies mature, or objectives are satisfied.

[2]NASA's Architecture Definition Document defines use cases as operations that would be executed to produce the desired needs and/or characteristics. It defines functions as actions that an architecture would perform to complete the desired use case.

New programs may formally enter the architecture via a new milestone the Strategy and Architecture Office has implemented, called Element Initiation. During Element Initiation, the mission directorate reviews whether a proposed element provides a solution to needs or gaps identified in the Moon to Mars architecture and determines whether to apply necessary resources to formulate that element. Element Initiation occurs in pre-formulation and moves programs that the Architecture Concept Review process initiated into the traditional NASA space flight program development life cycle. NASA initiated two new elements through this process in 2023: (1) a lunar surface habitation element, which may provide an initial home for astronauts on the moon, and (2) a lunar surface cargo lander element, which may deliver supplies and equipment to the moon.

Appendix III: Comments from the National Aeronautics and Space Administration

National Aeronautics and Space Administration

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

Reply to Attn of: Exploration Systems Development Mission Directorate

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

Dear Mr. Russell:

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to review and comment on the Government Accountability Office (GAO) draft report entitled, "NASA Artemis Programs: NASA Should Document and Communicate Plans to Address Gateway's Mass Risk" (GAO-24-106878), dated June 13, 2024.

NASA plans to build a sustained human lunar presence and ultimately travel to Mars through a series of flights known as Artemis. The Agency is developing the Gateway—a space station planned to orbit the Moon in support of lunar exploration. NASA committed to launching the Gateway initial capability by December 2027 in support of the Artemis IV flight. The launch will include the first components of the Gateway—the Power and Propulsion Element and the Habitation and Logistics Outpost.

NASA's Exploration Systems Development Mission Directorate (ESDMD) acknowledges the crucial role played by GAO in assessing instances of waste, fraud, or abuse within the Federal Government. ESDMD is dedicated to transparency and accountability. The Agency's goal is to fully cooperate with GAO, providing access to all relevant information and documentation necessary for its audits, evaluations, and investigations. During this audit, ESDMD provided 85 products and attended 14 requested interviews.

NASA appreciates GAO's understanding that development projects inherently operate in dynamic environments, marked by frequent changes, updates, and iterations. The landscape can swiftly evolve during the development cycle, posing difficulties in aligning with evolving requirements, timelines, and deliverables. Additionally, parallel development and resultant changing requirements are an inherent reality that requires adaptability and flexibility from all involved parties. As projects progress, stakeholders gain deeper insights necessitating adjustments to initial specifications. Effective management of changing requirements involves clear communication, diligent documentation, and collaborative decision-making to assess the impact on timelines, resources, and project scope. While accommodating changes may introduce challenges such as increased development time or additional costs, addressing evolving needs proactively can lead to a more robust final product.

In the draft report, GAO states that the current Gateway schedule baseline does not align with the September 2028 Artemis IV flight date; however, the program has a plan to support the Artemis IV flight. ESDMD is committed to maintaining accountability among contractors regarding project timelines, even in the face of schedule slippage of other elements. Adhering to agreed-upon dates for all contracts fosters discipline and ensures that all stakeholders are committed to meeting project milestones. Holding contractors accountable reinforces the importance of timely delivery and helps mitigate further delays by instilling a sense of urgency. Additionally, it enables project managers to identify bottlenecks early on and take corrective actions to realign the project trajectory. While flexibility may be necessary in certain circumstances, maintaining firm expectations for adherence to dates encourages a culture of responsibility and ultimately contributes to the overall success of the project. To effectively manage the Gateway program, NASA is committed to proactively addressing potential risks and the Agency Baseline Commitment. By prioritizing an earlier delivery date, NASA aims to ensure the program's prompt completion. This approach underscores our determination to mitigate identified risks and uphold our commitment to delivering the Gateway as efficiently as possible.

NASA uses an array of tools to track quality, progress, and performance against cost and schedule targets, which include, but are not limited to, Government mandatory inspection points, project-level cost and schedule joint confidence level informed commitments (including for major developmental upgrades), independent reviews at major life-cycle reviews and associated key decision points, documented and configuration-controlled mission definition baselines, risk assessments, independent Agency financial auditing (including a thirteenth consecutive unmodified or "clean" audit opinion in 2023), and Agency-led baseline performance and major program reviews. There are also independent reviews by the NASA Advisory Council, Aerospace Safety Advisory Panel, and various other ongoing reviews from Governmental oversight entities. This rigorous monitoring helps NASA maintain accountability and quality in its programs and projects.

The Artemis implementation is unique from other NASA activities in that the flexible architecture is a guiding principle within the Artemis Campaign, enabling NASA to adapt to changing requirements, leverage partnerships, and achieve sustainable and cost-effective human exploration of the Moon and beyond. By embracing flexibility and innovation, NASA aims to establish a robust infrastructure and lay the foundation for future exploration missions to Mars and beyond. The approach NASA is pursuing ensures that capabilities are developed to meet the needs of the architecture.

In the draft report, GAO makes one recommendation addressed to the NASA Administrator.

Specifically, GAO recommends the following:

Recommendation 1: The NASA Administrator, in coordination with ESDMD, should ensure that the Gateway program documents its overall mass management plan and shares it with its projects ahead of the program's planned September 2024 critical design-informed synchronization review.

Management's Response: NASA concurs with this recommendation.

The Gateway program is working closely with both its prime contractors for initial capability, Northrop Grumman and Maxar Space Systems (Maxar), to ensure the final mass of the Co-Manifested Vehicle aligns with the performance of the launch vehicle such that the spacecraft can perform a timely transit to near-rectilinear halo orbit with sufficient capability to meet mission requirements. Both Northrop Grumman and Maxar have developed internal processes to manage the mass of their respective spacecraft, and the Gateway program is actively working to document an encompassing mass management plan, placing special emphasis on cross system mass management and mission design.

The Gateway program is currently approaching the next major milestone in its life-cycle, the Critical Design Review (CDR), where it will evaluate the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk. The Gateway program plans to finalize its mass management plan prior to CDR. To help ensure this plan is comprehensive, a preliminary version is already being used to supplement the internal mass management processes of both contractors. Their feedback, along with any lessons learned, will be incorporated into the final revision to ensure an objective decision-making framework exists for mass management throughout the remainder of Gateway's development.

Estimated Completion Date: September 30, 2024.

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

Once again, thank you for the opportunity to review and comment on the subject draft report. If you have any questions or require additional information regarding this response, please contact Christine Solga at (202) 358-1238.

Sincerely,

NED PENLEY

Digitally signed by NED PENLEY
Date: 2024.07.15 09:36:30 -05'00'

Catherine A. Koerner

Accessible Text for Appendix III: Comments from the National Aeronautics and Space Administration

Reply to Attn of: Exploration Systems Development Mission Directorate

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

Dear Mr. Russell:

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to review and comment on the Government Accountability Office (GAO) draft report entitled, “NASA Artemis Programs: NASA Should Document and Communicate Plans to Address Gateway’s Mass Risk” (GAO-24-106878), dated June 13, 2024.

NASA plans to build a sustained human lunar presence and ultimately travel to Mars through a series of flights known as Artemis. The Agency is developing the Gateway—a space station planned to orbit the Moon in support of lunar exploration. NASA committed to launching the Gateway initial capability by December 2027 in support of the Artemis IV flight. The launch will include the first components of the Gateway—the Power and Propulsion Element and the Habitation and Logistics Outpost.

NASA’s Exploration Systems Development Mission Directorate (ESDMD) acknowledges the crucial role played by GAO in assessing instances of waste, fraud, or abuse within the Federal Government. ESDMD is dedicated to transparency and accountability. The Agency’s goal is to fully cooperate with GAO, providing access to all relevant information and documentation necessary for its audits, evaluations, and investigations. During this audit, ESDMD provided 85 products and attended 14 requested interviews.

NASA appreciates GAO’s understanding that development projects inherently operate in dynamic environments, marked by frequent changes, updates, and iterations. The landscape can swiftly evolve during the development cycle, posing difficulties in aligning with evolving requirements, timelines, and deliverables. Additionally, parallel development and resultant changing requirements are an inherent reality that requires adaptability and flexibility from all involved parties. As projects progress, stakeholders gain deeper insights necessitating adjustments to initial specifications. Effective management of changing requirements involves clear communication, diligent documentation, and collaborative decision-making to assess the impact on timelines, resources, and project scope. While accommodating changes may introduce challenges such as increased development time or additional costs, addressing evolving needs proactively can lead to a more robust final product.

In the draft report, GAO states that the current Gateway schedule baseline does not align with the September 2028 Artemis IV flight date; however, the program has a plan to support the Artemis IV flight. ESDMD is committed to maintaining accountability among contractors regarding project timelines, even in the face of

schedule slippage of other elements. Adhering to agreed-upon dates for all contracts fosters discipline and ensures that all stakeholders are committed to meeting project milestones. Holding contractors accountable reinforces the importance of timely delivery and helps mitigate further delays by instilling a sense of urgency. Additionally, it enables project managers to identify bottlenecks early on and take corrective actions to realign the project trajectory. While flexibility may be necessary in certain circumstances, maintaining firm expectations for adherence to dates encourages a culture of responsibility and ultimately contributes to the overall success of the project. To effectively manage the Gateway program, NASA is committed to proactively addressing potential risks and the Agency Baseline Commitment. By prioritizing an earlier delivery date, NASA aims to ensure the program's prompt completion. This approach underscores our determination to mitigate identified risks and uphold our commitment to delivering the Gateway as efficiently as possible.

NASA uses an array of tools to track quality, progress, and performance against cost and schedule targets, which include, but are not limited to, Government mandatory inspection points, project-level cost and schedule joint confidence level informed commitments (including for major developmental upgrades), independent reviews at major life-cycle reviews and associated key decision points, documented and configuration-controlled mission definition baselines, risk assessments, independent Agency financial auditing (including a thirteenth consecutive unmodified or "clean" audit opinion in 2023), and Agency-led baseline performance and major program reviews. There are also independent reviews by the NASA Advisory Council, Aerospace Safety Advisory Panel, and various other ongoing reviews from Governmental oversight entities. This rigorous monitoring helps NASA maintain accountability and quality in its programs and projects.

The Artemis implementation is unique from other NASA activities in that the flexible architecture is a guiding principle within the Artemis Campaign, enabling NASA to adapt to changing requirements, leverage partnerships, and achieve sustainable and cost-effective human exploration of the Moon and beyond. By embracing flexibility and innovation, NASA aims to establish a robust infrastructure and lay the foundation for future exploration missions to Mars and beyond. The approach NASA is pursuing ensures that capabilities are developed to meet the needs of the architecture.

In the draft report, GAO makes one recommendation addressed to the NASA Administrator.

Specifically, GAO recommends the following:

Recommendation 1: The NASA Administrator, in coordination with ESDMD, should ensure that the Gateway program documents its overall mass management plan and shares it with its projects ahead of the program's planned September 2024 critical design-informed synchronization review.

Management's Response: NASA concurs with this recommendation.

The Gateway program is working closely with both its prime contractors for initial capability, Northrop Grumman and Maxar Space Systems (Maxar), to ensure the final mass of the Co-Manifested Vehicle aligns with the performance of the launch vehicle such that the spacecraft can perform a timely transit to near-rectilinear halo orbit with sufficient capability to meet mission requirements. Both Northrop Grumman and Maxar have developed internal processes to manage the mass of their respective spacecraft, and the Gateway program is actively working to document an encompassing mass management plan, placing special emphasis on cross system mass management and mission design.

The Gateway program is currently approaching the next major milestone in its life-cycle, the Critical Design Review (CDR), where it will evaluate the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk. The Gateway program plans to finalize its mass management plan prior to CDR. To help ensure this plan is comprehensive, a preliminary version is already being used to supplement the internal mass management processes of both contractors. Their feedback, along with any lessons learned, will be incorporated into the final revision to ensure an objective decision-making framework exists for mass management throughout the remainder of Gateway's development.

Estimated Completion Date: September 30, 2024.

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

Once again, thank you for the opportunity to review and comment on the subject draft report. If you have any questions or require additional information regarding this response, please contact Christine Solga at (202) 358-1238.

Sincerely,

NED PENLEY

Digitally signed by
NED PENLEY Date: 2024.07.15
09:36:30 -05'00'

Catherine A. Koerner

Appendix IV: GAO Contact and Staff Acknowledgments

GAO Contact

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

Staff Acknowledgments

In addition to the contact named above, Kristin Van Wychen (Assistant Director); Erin Kennedy (Analyst-in-Charge); Lena Burleson; Susan Ditto; Lorraine Ettaro; Laura Greifner; Tonya Humiston; Jason Lee; Joe Mancina; Carrie Rogers; Sylvia Schatz; Kate Sharkey; Kevin Walsh; Alyssa Weir; and Robin Wilson made significant contributions to this report.

GAO's Mission

The Government Accountability Office, the audit, evaluation, and investigative arm of Congress, exists to support Congress in meeting its constitutional responsibilities and to help improve the performance and accountability of the federal government for the American people. GAO examines the use of public funds; evaluates federal programs and policies; and provides analyses, recommendations, and other assistance to help Congress make informed oversight, policy, and funding decisions. GAO's commitment to good government is reflected in its core values of accountability, integrity, and reliability.

Obtaining Copies of GAO Reports and Testimony

The fastest and easiest way to obtain copies of GAO documents at no cost is through our website. Each weekday afternoon, GAO posts on its website newly released reports, testimony, and correspondence. You can also subscribe to GAO's email updates to receive notification of newly posted products.

Order by Phone

The price of each GAO publication reflects GAO's actual cost of production and distribution and depends on the number of pages in the publication and whether the publication is printed in color or black and white. Pricing and ordering information is posted on GAO's website, https://www.gao.gov/ordering.htm.

Place orders by calling (202) 512-6000, toll free (866) 801-7077, or
TDD (202) 512-2537.

Orders may be paid for using American Express, Discover Card, MasterCard, Visa, check, or money order. Call for additional information.

Connect with GAO

Connect with GAO on Facebook, Flickr, Twitter, and YouTube.
Subscribe to our RSS Feeds or Email Updates. Listen to our Podcasts.
Visit GAO on the web at https://www.gao.gov.

To Report Fraud, Waste, and Abuse in Federal Programs

Contact FraudNet:

Website: https://www.gao.gov/about/what-gao-does/fraudnet

Automated answering system: (800) 424-5454 or (202) 512-7700

Congressional Relations

A. Nicole Clowers, Managing Director, ClowersA@gao.gov, (202) 512-4400, U.S. Government Accountability Office, 441 G Street NW, Room 7125, Washington, DC 20548

Public Affairs

Sarah Kaczmarek, Acting Managing Director, KaczmarekS@gao.gov, (202) 512-4800, U.S. Government Accountability Office, 441 G Street NW, Room 7149
Washington, DC 20548

Strategic Planning and External Liaison

Stephen J. Sanford, Managing Director, spel@gao.gov, (202) 512-4707
U.S. Government Accountability Office, 441 G Street NW, Room 7814, Washington, DC 20548