RETURNING TO THE MOON: KEEPING ARTEMIS ON TRACK

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE AND AERONAUTICS

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

OF THE

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C O N T E N T S

January 17, 2024

RETURNING TO THE MOON: KEEPING ARTEMIS ON TRACK

WEDNESDAY, JANUARY 17, 2024

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON SPACE AND AERONAUTICS,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to notice, at 10:03 a.m., in room 2318, Rayburn House Office Building, Hon. Frank Lucas [Chairman of the Committee] presiding.

COMMITTEE ON
SCIENCE, SPACE
AND TECHNOLOGY
CHAIRMAN FRANK LUCAS

SPACE AND AERONAUTICS SUBCOMMITTEE

HEARING CHARTER

"Returning to the Moon: Keeping Artemis on Track"

Wednesday, January 17, 2024
10:00 AM
2318 Rayburn House Office Building

Purpose

The Artemis program is the National Aeronautics and Space Administration (NASA) effort to return United States astronauts to the lunar surface. The purpose of this hearing is to monitor progress on Artemis objectives, identify and understand challenges faced by NASA, and discuss the agency's path forward. This hearing also will provide the Committee with valuable insight on how NASA plans to ensure a successful American return to the Moon and enable future exploration of Mars and beyond.

Witnesses

- **Ms. Catherine Koerner,** Associate Administrator, Exploration Systems Development Mission Directorate, National Aeronautics and Space Administration
- **Mr. William Russell,** Director, Contracting and National Security Acquisitions, U.S. Government Accountability Office
- **Mr. George A. Scott,** Acting Inspector General, National Aeronautics and Space Administration
- **Dr. Michael D. Griffin,** Co-President, LogiQ, Inc

Overarching Questions

- What elements of the Artemis program are on the critical path to launching Artemis II and III? What is the status of these elements?
- NASA recently announced the delay of Artemis II and III from 2024 and 2025 respectively, to 2025 and 2026. What was the cause of this change in schedule? What is the anticipated impact of this delay on Artemis program costs?

- How has NASA adapted to mitigate future schedule and cost overruns?
- What are the most significant technical challenges NASA has faced so far? What impact have NASA management decisions had on program execution? How is NASA learning from these experiences to better execute the Artemis program moving forward?
- Among the existing risks and challenges to the Artemis program, which present the highest risks to program cost, schedule, and mission success?

Background

The Artemis program represents the next generation of United States human space exploration beyond Earth orbit. While the immediate goal of the program is to land humans on the lunar surface for the first time since the Apollo program, the Artemis program seeks to establish sustainable, long-term access to the Moon. Doing so will both advance exciting scientific research and serve as a proving ground for future human space missions to Mars and other deep space destinations.

Today's Artemis program is the result of almost two decades of evolution that started in 2004. President George W. Bush and then-Administrator Michael Griffin released a Vision for Space Exploration establishing goals for the United States space program and calling for a return to the Moon.[1] Congress incorporated the ambitious objectives of the Vision into the 2005 NASA Authorization, directing NASA to return to the moon by 2020 to promote exploration, science, and commerce, and also to serve as a stepping-stone to Mars and other deep space destinations.[2] Each phase of exploration (Earth orbit, the Moon, and ultimately Mars) would build on the experience and lessons learned from earlier missions. Constellation hardware included Ares launch vehicles, an Earth Departure Stage secondary booster, an Orion spacecraft, and an Altair lunar lander.

In 2009, President Obama ordered a review of the Constellation program and acting Administrator Christopher Scolese established the "Review of U.S. Human Spaceflight Plans Committee", commonly referred to as the Augustine Commission. The Commission found that "since Constellation's inception the program has faced a mismatch between funding and program content" and that the funding strategy for Constellation relied on NASA retiring the Space Shuttle by 2010 and decommissioning the ISS by 2016.[3] The Commission proposed five alternative approaches for human space exploration, only two of which aligned with the Obama Administration's FY2010 budget profile for Constellation. Neither option would "permit human exploration to continue in any meaningful way", and ultimately the Obama Administration's FY2011 budget proposed cancellation of the Constellation program, shifting instead to an approach that would land humans on the surface of an asteroid.[4] While many elements of the Constellation program were abandoned, Congress directed NASA to develop a Space Launch System using "existing vehicle development and associated contracts" (*i.e.,* efforts formerly dedicated to the development of the Ares launch vehicle) and the Orion spacecraft.[5]

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[1] https://georgewbush-whitehouse.archives.gov/news/releases/2004/01/20040114-3.html
[2] https://www.congress.gov/bill/109th-congress/senate-bill/1281
[3] https://www.nasa.gov/wp-content/uploads/2015/01/617036main_396093main_HSF_Cmte_FinalReport.pdf
[4] https://www.sciencedirect.com/science/article/pii/S0265964610001189
[5] https://www.congress.gov/bill/111th-congress/senate-bill/3729/text

In 2017, Congress reiterated its continued support for the stepping-stone approach in the NASA Transition Authorization Act.[6] The Trump Administration was aligned on this position and issued Space Policy Directive-1 (SPD-1) directing NASA to "lead the return of humans to the Moon for long-term exploration and utilization."[7] This time, however, NASA would not go alone; per SPD-1, the revived effort would involve a team of commercial and international partners.

In September of 2018, NASA issued its National Space Exploration Campaign Report describing NASA's efforts to plan a human lunar landing in the late 2020s.[8] This objective was confirmed six months later in NASA's FY2020 budget request, which announced NASA's intent to return humans to the Moon by 2028. Vice President Michael Pence further accelerated this deadline, directing NASA to land humans on the south pole of the Moon by 2024. NASA's FY2021 budget request reflected both the Artemis program and the 2024 landing date set by the Vice President. NASA also published its Lunar Exploration Program Overview in 2020, which provided an overview of the agency's planned lunar exploration activities.[9]

The Biden Administration has continued progress on the Artemis program's return to the Moon.[10] In 2022, Congress also required that NASA establish a new Moon to Mars Program Office within ESDMD, charged with ensuring that Artemis missions fit within the human exploration roadmap and facilitate a human mission to Mars.[11]

Artemis Elements

Artemis-related activities can be found in multiple NASA mission directorates. The primary branch responsible for Artemis elements is the Exploration System Development Mission Directorate (ESDMD), but the Space Technology Mission Directorate (STMD) and the Science Mission Directorate (SMD) also play key roles. The major elements of the Artemis program are set forth below.

Space Launch System (SLS): SLS is a two-stage, super heavy-lift launch vehicle operated at the Kennedy Space Center. Derived from the Constellation program's canceled Ares V launch vehicle, SLS uses RS-25 engines and solid rocket boosters adapted from the Shuttle program. NASA plans for three different SLS configurations:

- Block 1 (which includes a core stage, Interim Cryogenic Propulsion Stage (ICPS), and solid rocket boosters).
- Block 1B (which retains the core stage and solid rocket boosters, but replaces the ICPS with the Exploration Upper Stage (EUS)).
- Block 2 (retains the core stage and the EUS, but replaces the solid rocket boosters with an upgraded model).

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[6] https://www.congress.gov/bill/115th-congress/senate-bill/442/text
[7] https://www.govinfo.gov/content/pkg/FR-2017-12-14/pdf/2017-27160.pdf
[8] https://www.nasa.gov/wp-content/uploads/2015/01/nationalspaceexplorationcampaign.pdf
[9] https://www.nasa.gov/wp-content/uploads/2020/12/artemis_plan-20200921.pdf
[10] https://www.space.com/biden-administration-commits-to-artemis-moon-landings
[11] https://www.congress.gov/bill/117th-congress/house-bill/4346

Each configuration will result in greater SLS lift capacity, with the Block 2 capable of lifting 130 metric tons to Low Earth Orbit.

Orion Spacecraft (Orion): The Orion multipurpose spacecraft is a crew vehicle designed to carry astronauts between Earth and deep space. Orion can sustain a crew for up to 21 days of space exploration. For Artemis missions, Orion will carry crew from Earth to lunar orbit, and then from lunar orbit back to Earth (transport to the lunar surface and back will be provided by the Human Landing System discussed below). Orion consists of three main components: a crew module, a service module, and a launch abort system.

Exploration Ground Systems (EGS): EGS manages the development and operation of Kennedy Space Center systems and facilities that support modern and next generation launch vehicles and spacecraft. For Artemis, EGS is responsible for the capabilities used to assemble, launch, and recover SLS and Orion, which includes integration of the SLS and Orion systems in preparation for launch.

Gateway: Gateway is a small, multi-purpose space station that will be placed in lunar orbit to serve as both a staging point for lunar expeditions and deep space exploration, as well as a platform for scientific research and technology demonstrations. NASA intends for Gateway to be an international effort, and anticipates partners providing additional habitation modules, external robotics, refueling capabilities and other contributions. The first four elements of Gateway are as follows:

- **Power and Propulsion Element (PPE):** PPE will provide power, thrust, and communications capabilities for Gateway.
- **Habitation and Logistics Outpost (HALO):** HALO provides basic habitation support infrastructure for Gateway, as well as additional docking ports for Orion and other spacecraft. HALO also can store cargo and other logistics deliveries that will support crewed missions.
- **International Habitat (I-Hab):** Like HALO, the I-Hab will provide additional spacecraft docking parts and living quarters for visiting astronauts. The I-Hab will be supplied by the European Space Agency (ESA).
- **ESPRIT Refueling Module (ERM):** ERM, also developed by ESA, will supply Gateway's propulsion system with fuel and also will provide additional storage space for cargo.

Human Landing System (HLS): HLS will dock either with Gateway or Orion and will transport astronauts from lunar orbit to the surface of the Moon and back to lunar orbit. NASA awarded contracts to build landing systems to two United States commercial providers. SpaceX, selected in 2021, will develop an HLS based on its Starship spacecraft that will be used for Artemis III and IV.[12] Following direction from Congress, NASA opened another HLS solicitation[13] and picked Blue Origin as a secondary HLS provider in 2023.[14]

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[12] https://www.nasa.gov/humans-in-space/nextstep-h-human-landing-system/
[13] https://www.nasa.gov/news-release/nasa-provides-update-to-astronaut-moon-lander-plans-under-artemis/
[14] https://www.nasa.gov/news-release/nasa-selects-blue-origin-as-second-artemis-lunar-lander-provider/

Space Suits: NASA requires new spacesuits that are suitable for deep space environments, including the lunar surface. While NASA initially planned to produce the suits internally, the agency shifted its acquisition approach and instead opted for a commercial procurement.[15] In June of 2022, NASA awarded contracts to Axiom Space and Collins Aerospace to produce new suits via the Exploration Extravehicular Activity Services (xEVAS) program.[16]

Artemis Missions

The Artemis missions use the elements described above to access deep space destinations, including lunar orbit, Gateway, and/or the lunar surface. Each Artemis mission is distinguished by a different number.

Artemis I launched from the Kennedy Space Center on November 16, 2022. This mission originally was scheduled to launch in November of 2018, but experienced years of delays caused by SLS and Orion manufacturing complications, technical issues (including hydrogen leaks found during SLS wet dress rehearsals), and other programmatic challenges.[17]

The mission was an uncrewed demonstration mission and the first test of the fully integrated SLS, Orion, and EGS systems. During the 25-day mission, NASA tested the Orion spacecraft by performing two lunar flybys before returning to Earth on December 11, 2022. Upon return, NASA conducted post-flight analysis indicating that the mission was successful and many systems performed better than expected.[18]

Artemis II will be the first crewed demonstration mission of the integrated SLS, Orion, and EGS systems. Over the course of ten days, astronauts onboard Orion will confirm that all spacecraft systems operate as designed and test performance of the crewed spacecraft in deep space. The Artemis II crew includes three NASA astronauts (Reid Wiseman, Victor Glover, and Christina Koch) as well as an astronaut from the Canadian Space Agency (Jeremy Hansen). NASA's original baseline commitment was to launch Artemis II in April 2023. NASA now estimates Artemis II will launch in September of 2025.

Artemis III will be a crewed lunar landing demonstration mission. After launch, the crew's Orion spacecraft will travel to lunar orbit where it will rendezvous with SpaceX's Starship HLS. Once docked, two astronauts will board the Starship HLS, which will disconnect from Orion and descend to the lunar surface. Astronauts will spend approximately one week on the Moon, performing a range of tasks including scientific experiments and technology demonstrations. The Starship HLS will then transport the two astronauts back to lunar orbit to join their colleagues on Orion for return to Earth. NASA estimates that Artemis III will launch in September of 2026.

Artemis IV will be the first Artemis mission to utilize the SLS Block 1B configuration, which includes the EUS. Astronauts will travel onboard the Orion to lunar orbit, where they will deliver

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[15] https://www.gao.gov/products/gao-22-105533
[16] https://www.space.com/nasa-selects-companies-build-spacesuits-moon-space-station
[17] https://www.smithsonianmag.com/science-nature/what-you-need-to-know-about-nasas-artemis-i-launch-180980654/
[18] https://www.nasa.gov/humans-in-space/analysis-confirms-successful-artemis-i-moon-mission-reviews-continue-2/

the I-Hab module to the Gateway. Then, two astronauts will board a Starship HLS and descend to the lunar service for a week of tasks, including collection of samples to bring back to Earth.

Artemis V, also using an SLS Block 1B, will deliver crew to lunar orbit and the ESPRIT module to Gateway. Two astronauts will again travel to the lunar surface to collect additional samples for return to Earth.

By the end of the 2020s, NASA intends to establish an SLS launch cadence of roughly one mission per year. NASA already is working to establish long-lead contracts to achieve this goal. For example, NASA has awarded a contract for the SLS solid rocket boosters that extends through Artemis XII.[19]

Key Issues

The Artemis program has already seen both cost and schedule growth from its established baseline commitments. Despite forward progress on Artemis program initiatives, there are a number of risks that NASA must mitigate moving forward. Establishing an improved understanding of project cost and schedule, finalizing design and technical requirements, and resolving contract and personnel management concerns will all be important matters to consider moving forward. Artemis also faces difficulties stemming from the maturity of technologies critical to future missions. Below is a summary of key issues identified in recent reports, reviews, and audits of the Artemis program.

Government Accountability Office (GAO)

NASA Artemis Programs: Crewed Moon Landing Faces Multiple Challenges

GAO released a November 2023 report evaluating NASA's plan to complete a lunar landing on the Artemis III mission.[20] The report highlighted multiple challenges, including delays in the development of the lunar lander and spacesuits needed for the mission. The report concluded that a variety of factors, particularly the readiness of HLS, made a 2025 lunar landing unlikely. The challenges GAO identified include:

- An overly ambitious development schedule for the HLS program: GAO estimated that NASA's launch date was 13 months too short when compared to NASA's usual rate of production. If HLS development follows the average speed for major NASA projects, GAO estimated that HLS would not be ready for launch until early 2027.
- Delays in critical milestones: GAO found that 8 of 13 key events for the HLS program had been delayed by at least 6 months. SpaceX attempted a Starship Orbital Test Flight in April of 2023, but the flight was terminated early by the FTS system. Many subsequent tests are contingent on a successful Orbital Flight Test, causing strain on the already-compressed development timeline.
- Multiple novel and complex technical capabilities critical to the HLS design have yet to be matured: SpaceX must complete a large volume of complex technical work for HLS, especially in the areas of on-orbit propellant transfer and storage.

[19] NASA's Artemis Moon Missions: all you need to know (rmg.co.uk)
[20] https://www.gao.gov/products/gao-24-106256

NASA Lunar Programs: Improved Mission Guidance Needed as Artemis Complexity Grows

GAO released a September 2022 report assessing NASA's mission-level management for the Artemis program, including its development of mission schedules and mission-level reviews.[21] The report identified the following concerns:

- NASA lacks "agency-wide, mission-level schedule management guidance to inform realistic integration schedules and launch dates for Artemis missions." NASA instead adapts guidance that was developed for program-level schedule management rather than mission-level.
- NASA has yet to conduct a Schedule Risk Analysis (SRA) for Artemis II.
- NASA has not developed a mission-level schedule for Artemis III.
- While NASA conducts workforce planning, it does not perform any advance workforce planning beyond five budget years. NASA already has committed billions of dollars for Artemis contracts that extend well beyond this five-year window. NASA risks facing a shortage of skilled laborers needed for future Artemis activities.

GAO recommended that NASA:

- Direct the NASA Chief Financial Officer to coordinate with mission directorates for development of mission-level schedule management guidance for Artemis.
- Conduct a schedule risk analysis for the Artemis II mission and update it as needed to incorporate schedule updates and new risks.
- Develop guidance for division-level schedule collaboration on Artemis III and subsequent missions.
- Ensure that the NASA Office of the Chief Human Capital Officer develops guidance identifying a regular and recurring process for long-term Artemis workforce scenario planning at least 5 years beyond the existing 5-year workforce plans.

Other Reports

GAO has released several reports regarding the Artemis program. In an analysis of SLS cost transparency, GAO stated:

> "NASA does not plan to measure production costs to monitor the affordability of the SLS program. After SLS's first launch, Artemis I in November 2022, NASA plans to spend billions of dollars to continue producing multiple SLS components, such as core stages and rocket engines, needed for future Artemis missions. These ongoing production costs to support the SLS program for Artemis missions are not captured in a cost baseline, which limits transparency and efforts to monitor the program's long-term affordability."[22]

When reviewing programmatic challenges of Artemis I through III, GAO noted that, due to the sequential links between each of the first three missions, delays to one mission will have cascading

[21] https://www.gao.gov/products/gao-22-105323
[22] https://www.gao.gov/products/gao-23-105609

cost and schedule impacts for the other missions.[23] Further, the minimum time required between Artimis I and II, and Artemis II and III limits NASA's ability to mitigate the effects of these delays. GAO also highlighted a noticeable lack of cost and schedule baselines for many Artemis projects, which creates challenges in assessing the progress and affordability of the program. For example, Orion does not have a cost and schedule baseline past Artemis II.

NASA Inspector General

NASA's Management of the Artemis Supply Chain

NASA OIG issued a report in October of reviewing NASA's management of the Artemis supply chain and analyzing problems.[24] NASA IG noted that, while many of the challenges it identified were outside of NASA's control, "the Agency lacks visibility into its critical suppliers with many Artemis programs and projects not tracking their prime contractors' supply chain impacts." Additionally, the IG found that Artemis programs and projects were not taking advantage of NASA's Logistics Management Division (LMD) when addressing supply chain issues. More generally, the report noted that NASA's project management practices fell short of other government agencies conducting major projects. It also concluded that NASA's efforts to improve supply chain visibility thus far have been ineffective.

The NASA IG provided many recommendations for NASA, including suggestions that NASA:

- Provide training and resources to ensure that contracting officers utilize available supplier data.
- Centralize supply chain management for the Artemis campaign within the Moon to Mars Program Office.
- Incorporate a representative from LMD into each Artemis-related program.
- Ensure an Artemis-specific industrial base and supply chain study is completed on a recurring basis.

NASA's Partnerships with International Space Agencies for the Artemis Campaign

In January of 2023, NASA OIG issued a report assessing NASA's plans for international cooperation and identifying impediments to execution of international partnerships.[25] The report found:

- NASA lacks a comprehensive, overarching strategy to coordinate international contributions for the Artemis program.
- NASA lacks comprehensive forums (e.g., boards, panels, and working groups) to facilitate Artemis-related discussions with international partners.
- U.S. export control regulations present an obstacle, as such regulations "can be overly complex and restrictive, and their implementation in international agreements, policies, and how space flight systems are classified routinely limit NASA's international

[23] https://www.gao.gov/products/gao-22-105533
[24] https://oig.nasa.gov/docs/IG-24-003.pdf
[25] https://oig.nasa.gov/docs/IG-23-004.pdf

collaborations on Artemis." Further, "the Artemis campaign lacks a unique EAR classification of specific space flight items or consistent jurisdiction and classification of Artemis elements, such as the Orion spacecraft, that would simplify the timely exchange of space flight items and technical information with international partners."

Select recommendations from the report suggest that NASA leadership:

- Establish NASA-led Artemis campaign boards and working groups for partners with agreed-upon commitments and provide opportunities for liaison representation from international partner agencies.
- Perform a detailed gap analysis and cost estimate for Artemis missions beyond Artemis IV that will help inform a cost-sharing strategy with international partners.
- Review export control requirements and consider additional roles for partner astronauts to increase their utilization in NASA space flight operations.
- Execute Artemis agreements with key international space agency partners to ensure partner roles and responsibilities are clearly understood and allow for efficient and timely partnerships in support of Artemis.

NASA's Management of the Space Launch System Booster and Engine Contracts

Issued in May of 2023, this NASA OIG report explored performance of the Boosters and Adaptation contracts and reviewed the impact of Booster Production and Operations Contract (BPOC) and R-25 Restart and Production efforts to improve Artemis program cost management.[26] The IG found the following:

- NASA continues to face substantial cost growth, and schedule delays in the Artemis program that could impact technology design. Despite this, NASA concurrently is developing and producing engines and boosters. This conflicts with the established best practice of completing development before moving to production.
- Marshall Space Flight Center (MSFC) procurement officials charged with overseeing all four Artemis program contracts "are challenged by inadequate staff, their lack of experience, and limited opportunities to review contract documentation."
- NASA opted to use cost-plus contracts for projects where fixed-price contracts could potentially have reduced costs, including for added production engines under the RS-25 Restart and Production contract and acquisition of long-lead materials under the BPOC letter contract.

Select recommendations from the report suggest that NASA leadership:

- Assess whether the 18 new production engines under the RS-25 Restart and Production contract can be acquired through a fixed-price contract.
- Identify procurement needs and resources available to address MSFC staff shortages, and ensure that MSFC officials comply with best practices for establishing and maintaining

[26] https://oig.nasa.gov/docs/IG-23-015.pdf

internal controls related to requests for equitable adjustment of award fee payments, fiscal law, and appropriate internal and external engagement.

- Update the cost-per-engine estimate for RS-25 engines to include investments made in production restart.
- Develop a separate non-fee bearing contract line item for completion of the unfinished adaptation of heritage RS-25 engines.

Figures

The following figures provide additional information on the Artemis program, including budget estimates, program elements, and mission profiles.

Budget Charts

Artemis Campaign Development

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Gateway	742.5	--	**914.2**	853.0	744.2	768.8	777.3
Adv Cislunar and Surface Capabilities	70.1	--	**60.3**	102.0	433.0	563.8	969.9
Human Landing System	1,195.0	1,485.6	**1,880.5**	2,224.7	2,286.7	2,748.3	2,526.6
xEVA and Human Surface Mobility Program	0.0	275.9	**379.9**	494.8	605.0	605.3	605.7
Total Budget	**2,007.6**	**2,600.3**	**3,234.8**	**3,674.4**	**4,068.9**	**4,686.2**	**4,879.6**

Figure 1: NASA budget request for Artemis Campaign Development for FY2024 to FY2028 (source: NASA FY2024 budget request)

Artemis Program Components

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Orion Program	1,401.7	1,338.7	**1,225.0**	1,093.7	1,093.7	1,094.2	1,115.1
Crew Vehicle Development	1,388.8	1,320.3	**1,212.6**	1,058.7	1,058.7	1,058.5	1,062.5
Orion Program Integration and Support	12.9	--	**12.5**	34.9	35.0	35.7	52.7
Space Launch System	2,600.0	2,600.0	**2,506.1**	2,483.3	2,322.4	1,917.1	1,969.1
Launch Vehicle Development	2,526.9	2,361.4	**2,427.2**	2,365.8	2,206.7	1,804.6	1,798.8
SLS Program Integration and Support	73.1	--	**78.9**	117.5	115.7	112.5	170.3
Exploration Ground Systems	589.0	799.2	**794.2**	664.7	593.2	546.0	445.5
Exploration Ground Systems Development	398.1	330.6	**273.2**	143.5	81.8	15.6	0.0
EGS Program Integration and Support	190.9	--	**521.0**	521.2	511.4	530.4	445.5
Construction & Envrmtl Compl Restoration	90.3	--	**10.5**	0.0	0.0	0.0	0.0
Exploration CoF	90.3	--	**10.5**	0.0	0.0	0.0	0.0
Total Budget	**4,681.0**	**4,824.1**	**4,535.9**	**4,241.7**	**4,009.3**	**3,557.3**	**3,529.7**

Figure 2: NASA budget request for Orion, SLS, and EGS for FY2024 to FY2028 (source: NASA FY2024 budget request)

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**0.0**	**--**	**49.1**	**50.0**	**50.5**	**51.0**	**51.1**

Figure 3: NASA budget request for Moon to Mars Architecture for FY2024 to FY2028 (source: NASA FY2024 budget request)

Budget Authority (in $ millions)	Op Plan FY 2022	Enacted FY 2023	Request FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Total Budget	**187.4**	**--**	**161.8**	**164.4**	**164.4**	**164.5**	**167.8**

Figure 4: NASA budget request for Mars Campaign Development for FY2024 to FY2028 (source: NASA FY2024 budget request)

Artemis Operational Costs

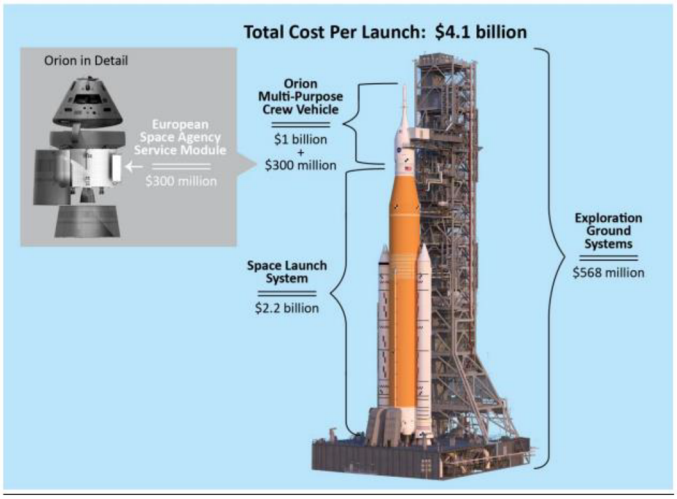


Figure 5: NASA estimate of SLS and Orion Operating Costs Per Launch (Source: NASA OIG)

Artemis Schedule

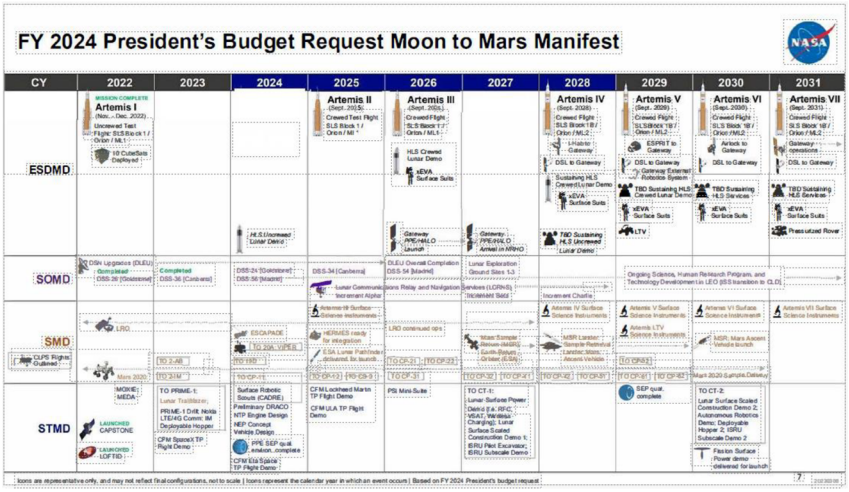


Figure 6: NASA schedule for Artemis and associated missions (Source: NASA)

Artemis Architecture

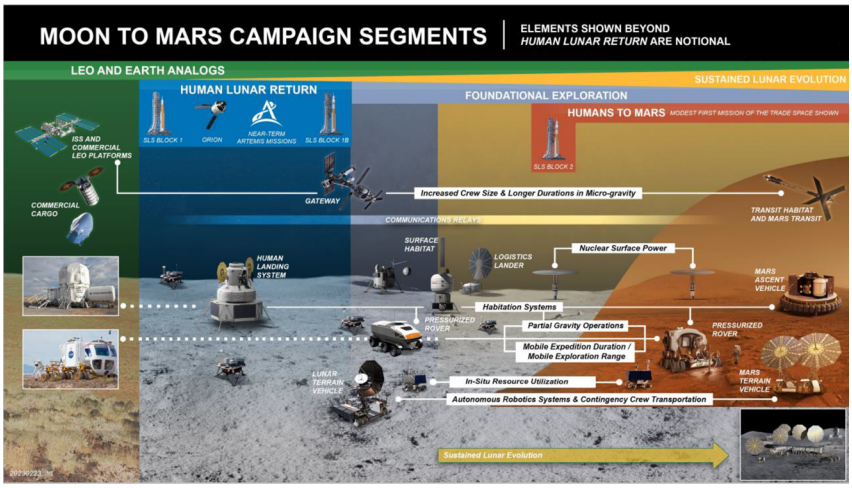
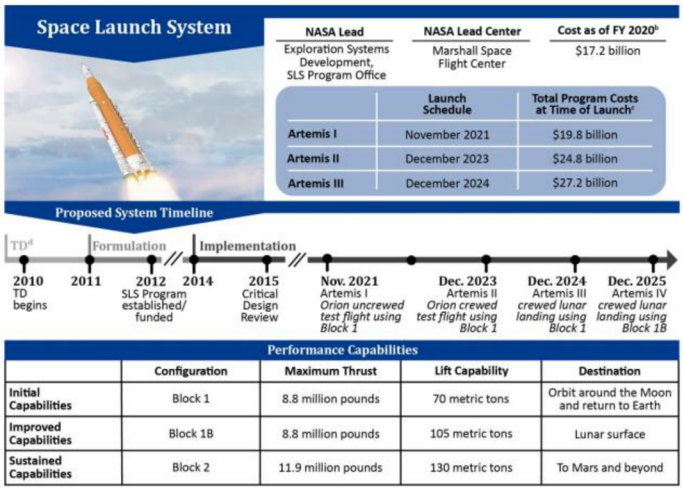


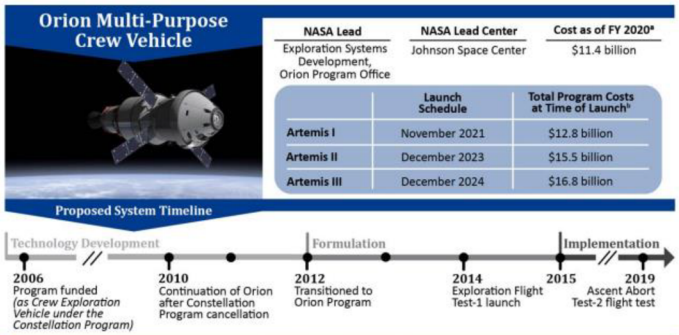
Figure 6: NASA Architecture for human deep space exploration (Source: NASA)

Artemis Components



Performance Capabilities				
	Configuration	Maximum Thrust	Lift Capability	Destination
Initial Capabilities	Block 1	8.8 million pounds	70 metric tons	Orbit around the Moon and return to Earth
Improved Capabilities	Block 1B	8.8 million pounds	105 metric tons	Lunar surface
Sustained Capabilities	Block 2	11.9 million pounds	130 metric tons	To Mars and beyond

Figure 6: SLS overview and development plan (Source: NASA OIG)



Performance Capabilities

	Number of Crew	Mission Duration	Habitable Volume	Docking Capability	Abort Capability	Life Support	Return Entry Velocity
Initial Capabilities *(Artemis I)*	0	21 to 42 days	316 cubic feet	None	Limited	Limited	+36,000 feet per second
Sustained Capabilities *(Artemis III and beyond)*	4	21 days	316 cubic feet	Gateway or Human Landing System	Full	Full	+36,000 feet per second

Figure 7: Orion overview and development plan (Source: NASA OIG)

Performance Capabilities

	Launch Readiness Date	Mission	Type of Rocket/System	Launch Capacity
Initial Capabilities *(Mobile Launcher 1)*	November 2021	Artemis I, II, and III	SLS Block 1 configuration and Orion	Up to two per year
Sustained Capabilities *(Mobile Launcher 2)*	December 2025	Artemis IV and beyond	SLS Block 1B and 2 configuration and Orion	Up to two per year

Figure 8: EGS overview and development plan (Source: NASA OIG)

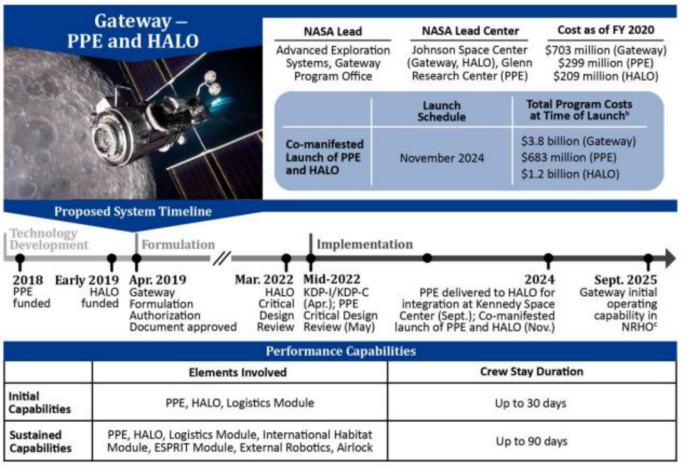


Figure 9: Gateway overview and development plan (Source: NASA OIG)

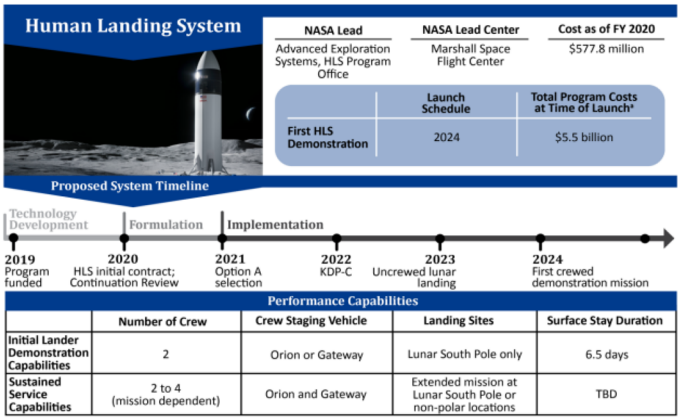
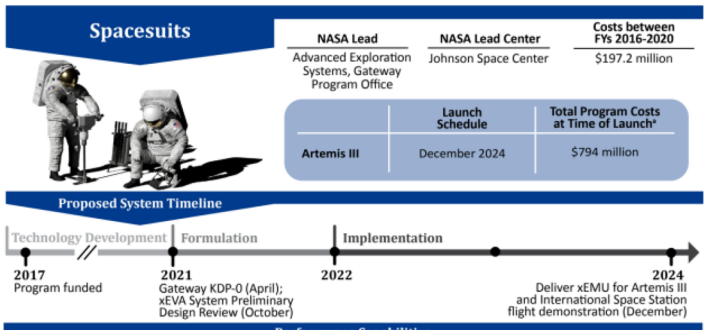


Figure 10: HLS overview and development plan (Source: NASA OIG)



Performance Capabilities

	Flight Hardware	Suited Training Event *(supports NASA's training of crew on systems and development of EVA task content)*	Number of EVAs
Initial Capabilities *(ISS EVA Demonstration)*	Hardware for 4 crewmembers	60 events	TBD
Sustained Capabilities *(ISS EVA Service)*	Hardware for 10 crewmembers	80 events per mission plus 5 events per EVA	10 per year
Initial Capabilities *(Artemis EVA Demonstration)*	Hardware for 4 crewmembers	160 events	5 per mission
Sustained Capabilities *(Artemis EVA Service)*	Hardware for 4 to 8 crewmembers	160 events	5 per mission

Figure 11: Spacesuits overview and development plan (Source: NASA OIG)

Chairman LUCAS. The Subcommittee on Space and Aeronautics will come to order. Without objection, the Chair is authorized to declare recess of the Subcommittee at any time.

Welcome to today's hearing entitled "Returning to the Moon: Keeping Artemis on Track." And before I make—offer my opening statement, I would like to acknowledge that I appreciate our witnesses being here today. Mother Nature is proving to be somewhat challenging this week, as you can see by the turnout of membership. This has been a hearing that's been much anticipated by the Members in a very enthusiastic way, but you have to physically get here. And that's a challenge we're working on. And Subcommittee Chairman Babin is in the air somewhere between here and Houston, so the moment he arrives, we will have a proper Chairman to preside over this process.

With that, I want to recognize myself for five minutes for an opening statement.

Good morning, and I welcome everyone to the Science Committee's first hearing of 2024. It's fitting that we're kicking off the year with a hearing on Artemis, given its importance to our space program and to U.S. competitiveness. My top priority since becoming Chairman of the Science Committee has been to ensure that American competitiveness and leadership in the fields of research and technology development. This includes U.S. activities in space, especially human exploration.

The importance of U.S. leadership in space is why some of our top legislative priorities this Congress include a NASA (National Aeronautics and Space Administration) reauthorization bill, which we'll consider this spring, and the *Commercial Space Act.* It has been almost seven years since a comprehensive NASA authorization bill was signed into law, and that's simply too long for an agency of NASA's importance.

Much has happened during that period, and this Committee should provide direction to NASA's activities for the coming years, especially in the areas of human exploration. How we address future human exploration beyond low Earth orbit is undoubtably a topic we'll address in the NASA authorization bill. Artemis is a cornerstone of that effort. I'm confident that I speak for everyone on this Committee when I say we all support Artemis. This Committee has long directed NASA to return humans to the Moon and eventually Mars. But this Committee's support of Artemis means asking detailed questions of NASA and providing oversight of the agency's proposals. Congress must have proper insight in the agency's planning and execution of this mission to ensure its success.

This also means listening to inputs from external stakeholders and hearing differing viewpoints, which is why we've assembled a panel of witnesses with a variety of perspectives today.

Last week, NASA announced the delay of Artemis II to September 2025 and Artemis III to September 2026. I look forward to hearing from NASA about the cause of these delays and potential impacts to future missions and about the steps it is taking to mitigate future risks. We have a responsibility to not only our constituents, but the international community to see that Artemis is executed in a timely and fiscally responsible manner without sacrificing safety.

I remind my colleagues that we are not the only country interested in sending humans to the Moon. The Chinese Communist Party is actively solicitating international partners for a lunar mission, a lunar research station, and has stated its ambition to have astronauts on—human astronauts on the surface by 2030. The country that lands first will have the ability to set a precedent for whether future lunar activities are conducted with openness and transparency or in a more restricted manner.

I'm grateful to our panel for appearing before us today to share their experience and expertise, and I look forward to a productive discussion on how we can ensure the success of Artemis and the best way for the U.S. to be the world leader in human space exploration.

[The prepared statement of Chairman Lucas follows:]

Good morning. I want to welcome everyone to the Science Committee's first hearing of 2024. It's fitting that we're kicking off the year with a hearing on Artemis, given its importance to our space program and to U.S. competitiveness.

My top priority since becoming chairman of the Science Committee has been to ensure American competitiveness and leadership in the fields of research and technology development. This includes U.S. activities in space, especially human exploration.

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I now recognize Ranking Member Sorensen for his opening statement.

Chairman LUCAS. I now recognize Ranking Member Sorensen for his opening statement.

Mr. SORENSEN. Good morning. Thank you, Chairman Lucas, for holding today's hearing "Returning to the Moon: Keeping Artemis on Track." I want to welcome our distinguished witnesses. Thank you for your time and your expertise and for being here today.

I was not alive, huddled around the TV for Apollo 11, but my parents watched that landing. I'm the son of an aerospace engineer and a meteorologist with a deep love of science. I know the profound impact it has had on our country and on our world. When I look up in the night sky, I wonder what's up there. I want us to know what's up there.

Today, we're examining NASA's Artemis mission. The program, separated into several stages, is designed to bring humans step by step to the Moon and beyond. Artemis will inspire the next generation, strengthen our aerospace industry and international partnerships, and demonstrate capabilities needed to eventually send humans to Mars.

Last year, I was proud to host NASA astronaut Dr. Kate Rubins in my district in western Illinois. Dr. Rubins spoke about her excitement for the upcoming generation. She believes that—and I spoke with our witnesses earlier—that the first humans that will set foot on Mars may be in a first grade classroom today. What an exciting possibility for the next generation, for our children.

The Artemis I mission was an important first uncrewed test that sent the Orion vehicle thousands of miles beyond the Moon before its return to Earth. Artemis II will test additional systems as it brings humans around the Moon, and Artemis III will land humans back on the lunar surface.

The difficulty of these missions cannot be underestimated. Last week, we learned that NASA's delaying the Artemis II and III missions by about a year. I stand behind NASA in prioritizing safety for Artemis, and I look forward to gaining further insight into the delays and any related costs.

Artemis requires a sustained national investment. In a 2021 report, the NASA Office of the Inspector General (IG) said, quote, "NASA is projected to spend $93 billion on the Artemis effort from Fiscal Year 2012 to 2025," end quote. And that's even before we land our astronauts on the Moon. As authorizers with oversight responsibility, this Committee needs to ensure that those investments are made wisely.

This hearing provides a timely opportunity to get both an update on the progress and an understanding of the pressing issues of the Artemis program, including does NASA and Congress have an appropriate level of understanding of the cost of key Artemis systems, individual Artemis missions, and a sustained lunar exploration effort? What is the critical path for returning humans to the Moon? And what is the plan for addressing all of the challenges? How would a fiscal 2024 budget at enacted 2023 levels or even a cut below the 2023 levels affect this program? How are NASA and its partners addressing risks? And how will risk be communicated to the American people?

In closing, Mr. Chairman, I want the Artemis to be safe and successful. Artemis and Moon to Mars are tremendous opportunities and of importance to the United States and the rest of the world. America's international leadership and engagement in the Artemis

program and the Artemis Accords will promote peaceful, safe, and sustainable exploration of the Moon and other celestial bodies.

Thank you, and I yield back the balance of my time, Chairman.

[The prepared statement of Mr. Sorensen follows:]

Good morning and thank you, Chairman Lucas, for holding today's hearing *Returning to the Moon: Keeping Artemis on Track.*

I want to welcome our distinguished witnesses. Thank you for being here.

I was not alive during the Apollo 11 landing, but as the son of an aerospace engineer, and a meteorologist with a deep love of science, I know the profound impact it has had on our country and on the world. When I look up at the night sky, I wonder what is up there? I want us to go so I can know.

Today, we are examining NASA's Artemis program. This program, separated into several stages, is designed to bring humans, step by step, to the moon and beyond.

Artemis will inspire the next generation, strengthen our aerospace industry and international partnerships, and demonstrate capabilities needed to eventually send humans to Mars.

Last year, I was proud to host NASA astronaut, Dr. Kate Rubins, in my district. Dr. Rubins spoke about her excitement for the upcoming generation. She believes that first graders are the perfect age to one day go to Mars. What an exciting possibility for our nation's children!

The Artemis I mission was an important first uncrewed test and sent the Orion vehicle thousands of miles beyond the Moon before its return to Earth. Artemis II will test additional systems as it brings humans around the moon. And Artemis III will land humans back on the moon. The difficulty of these missions cannot be underestimated.

Last week, we learned that NASA is delaying the Artemis II and Artemis III missions by about a year. I stand behind NASA in prioritizing safety for Artemis, and I look forward to gaining further insight into the delays and any related costs.

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As authorizers with oversight responsibility, this committee needs to ensure those investments are made wisely.

This hearing provides a timely opportunity to get both an update on the progress and an understanding of the pressing issues for the Artemis program, including,

- Do NASA and Congress have an appropriate level of understanding of the cost of key Artemis systems, individual Artemis missions, and a sustained lunar exploration effort?
- What is on the critical path for returning humans to the Moon and what is the plan for addressing those challenges?
- How would an FY2024 budget at enacted FY2023 levels, or even a cut below the FY 2023 appropriated levels, affect the Artemis program?
- How are NASA and its partners addressing risks and how will risk be communicated to the public?

In closing, Mr. Chairman, I want Artemis to be safe and successful. Artemis and Moon to Mars are of tremendous importance to the United States and the world.

America's international leadership and engagement in the Artemis program and the Artemis accords will promote peaceful, safe, and sustainable exploration of the Moon and other celestial bodies.

Thank you, and I yield back the balance of my time.

Chairman LUCAS. Thank you, Mr. Sorensen.

I now recognize the Ranking Member of the Full Committee for a statement.

Ms. LOFGREN. Thank you. Good morning, and thank you, Mr. Chairman, for holding today's hearing. I want to welcome our witnesses, and thank you for being here to discuss the topic of "Returning to the Moon: Keeping Artemis on Track."

This Committee, as the Chairman has noted, has long maintained its bipartisan support for Artemis in the NASA's Moon to Mars efforts, and I don't see that changing in any way. I was thrilled with the success of the Artemis I test flight. In my own State of California, NASA's Moon to Mars campaign supports

11,600 jobs and created an economic impact of $2.8 billion according to NASA's 2021 Economic Impact Report.

So let me be clear, I support Artemis, but I want it to be successful, especially with China at our heels, and we need—we want to be helpful here in the Committee in ensuring that Artemis is strong and staying on track as we look to lead the world hand-in-hand with our partners in the human exploration of the Moon and beyond.

Now, sending people into space, let alone the Moon, isn't easy. And NASA recently announced delays to the Artemis II and III missions. I have confidence in NASA's workforce and the decision to keep safety as a top priority. To that end, I look forward to understanding the details behind the recent delays and what's involved in addressing those issues.

As the Artemis efforts continue, we as the authorized Committee must have our eyes wide open. Moon to Mars is a multidecadal effect—effort that will span several Congresses and Administrations. Full situational awareness requires that, one, we know how much the key Artemis systems cost, as well as the missions themselves; two, have a realistic understanding of how NASA is assessing schedule; and three, have clarity on the top most technical challenges and risks and how they're being addressed across NASA and among its diverse set of partners and acquisition mechanisms.

We also know NASA has a lot on its plate. The future of low Earth orbit and the planned end of the International Space Station operations in 2030, the need for critical yet costly deorbit vehicle, the transition to the use of future commercial space stations and their readiness to come online, all this has to be kept in mind.

In addition, key considerations on the Mars sample return are on the horizon. And as we learned last week from NASA and NOAA's (National Oceanic and Atmospheric Administration's) annual assessment of global temperature, we must continue to obtain the measurements and observations needed to understand and mitigate the impacts of climate crisis.

In short, NASA is a multi-mission agency, and we can't lose sight of the benefits and challenges of a balanced portfolio. But supporting balance won't be made any easier by the dysfunctional appropriations process that I think threatens to undermine what we know is best for the—for leading the world and growing our economy in a sustainable way, investments in R&D (research and development) and innovations such as those at NASA.

I'm excited about Artemis and Moon to Mars, and I look forward to working with our Chairman, with the Administration, and with stakeholders on building a smart, strong, and sustainable path forward.

And I thank you, Mr. Chairman, and I yield back.

[The prepared statement of Ms. Lofgren follows:]

Good morning, and thank you, Chairman Babin, for holding today's hearing. I also want to welcome our witnesses. Thank you for being here to discuss the topic of "Returning to the Moon: Keeping Artemis on Track."

The Committee has long maintained its bipartisan support for Artemis and NASA's Moon to Mars efforts, and I don't see that changing in any way. I was thrilled with the success of the Artemis I test flight. In my own state of California, NASA's Moon to Mars campaign supports 11,600 jobs and created an economic impact of 2.8 billion dollars, according to NASA's FY2021 Economic Impact Report.

So let me be clear upfront. I support Artemis. I want it to be successful, especially with China at our heels. We want to be helpful in ensuring Artemis is strong and staying on track as we look to lead the world, hand in hand with our partners, in the human exploration of the Moon and beyond.

Sending people into space, let alone to the Moon, will never be easy. NASA recently announced delays to the Artemis II and III missions. I have full confidence in NASA's workforce and the decision to keep safety as the top priority. To that end, I look forward to understanding the details behind the recent delays and what is involved in addressing the issues.

As Artemis efforts continue, it's incumbent upon us, as the authorizing committee, to have our eyes wide open. Moon to Mars is a multi-decadal effort that will span several Congresses and Administrations.

Full situational awareness requires that:

1) We know how much the key Artemis systems cost, as well as the missions themselves;

2) Have a realistic understanding of how NASA is assessing schedule;

3) Have clarity on the topmost technical challenges and risks and how they are being addressed across NASA and among its diverse set of partners and acquisition mechanisms.

Moreover, we can't ignore that NASA has a lot on its plate. The future of low Earth orbit and the planned end of International Space Station operations in 2030, the need for a critical yet costly deorbit vehicle, the transition to the use of future commercial space stations and their readiness to come online must be kept in mind. In addition, key considerations on Mars Sample Return are on the horizon. And, as we learned last week from NASA and NOAA's annual assessment of global temperature, we must continue to obtain the measurements and observations needed to understand and mitigate the horrific impacts of the climate crisis. In short, NASA is a multi-mission agency, and we can't lose sight of the benefits and challenges of a balanced portfolio.

Supporting balance won't be made any easier by the dysfunctional appropriations process that threatens to undermine what we know is best for leading the world and growing our economy in a sustainable way—investments in R&D and innovation such as those at NASA.

I'm excited about Artemis and Moon to Mars. I look forward to working with the Chairman, the Administration, and stakeholders on building a smart, strong, and sustainable path forward.

Thank you, and I yield back.

Chairman LUCAS. The gentlelady yields back.

The Chair would note that when Subcommittee Chairman Babin arrives, we will make his time for an opening statement, too.

[The prepared statement of Mr. Babin follows:]

Good morning. I want to welcome everyone to the Science Committee's first hearing of 2024. It's fitting that we're kicking off the year with a hearing on Artemis, given its importance to our space program and to U.S. competitiveness.

The nation that leads in space earns tremendous scientific knowledge, reaps the rewards of technological advancements, and sets the rules of the road for future exploration. It's critical that we continue to lead so that our values of transparency, openness, and freedom guide exploration rather than communist principles and dictatorial regimes. That's why it's so important for Artemis to succeed.

The origins of the Artemis program stem from President Bush's Vision for Space Exploration, announced in January of 2004. In 2005, this committee directed NASA to plan to return American astronauts to the Moon as a stepping-stone to Mars and beyond. This committee, and Congress as a whole, has not wavered in its commitment to that goal. All too often NASA programs have suffered from cost over-runs, under-performance, schedule delays, or changing political directions that have led to cancellations. Recognizing this history, Congress has provided ″continuity of purpose″ for Artemis through multiple NASA Authorization Acts, robust appropriations, and consistent oversight to ensure the program remained focused across several Administrations.

This was no small task, and we still have our work cut out for us to maintain the program and ensure success. I was incredibly pleased to see the success of Artemis' first mission in November of 2022, which sent an uncrewed Orion capsule around the Moon and back to Earth, where it was successfully recovered in the Pacific Ocean. But last week, NASA announced delays to the Artemis 2 mission, which would send astronauts around the Moon, and the Artemis 3 mission, which would return humans to the lunar surface for the first time in more than 50 years.

Artemis 2 has been delayed until September 2025 and Artemis 3 has been pushed back to September 2026. This is in addition to proposed delays to Artemis 4 that were included in the President's Fiscal Year 2024 budget request last year. While an argument could be made that those schedules were aggressive, it is important for Congress to monitor contract performance and NASA program management to gain insight into trends and indicators that could portend future issues.

Every delay costs the United States time and taxpayer dollars and risks our preeminent role in space exploration. As I said at the beginning of my remarks, we cannot afford to cede U.S. leadership in space, so it's critical that we keep Artemis on track and on time.

That is the focus of the hearing today. My goal is for this Committee to come away with a better understanding of the current challenges facing Artemis and our efforts to return to the Moon.

There are plenty of topics for us to explore today ranging from acquisition strategies, architecture decisions, concept of operation choices, contractor performance, and NASA oversight. While we will only touch the surface of these complicated issues today, we will surely continue our oversight through additional hearings, information requests, budget reviews, and stakeholder engagement.

Today, however, we have witnesses from NASA, the Government Accountability Office (GAO), the NASA Inspector General, and the private sector, all of whom can give us more insight into the program and what's needed to keep it moving forward on time and on budget.

I look forward to their testimony, and discussing how we can ensure future success. Thank you.

Chairman LUCAS. Let me introduce our witnesses. Our first witness today is Catherine Koerner, Associate Administrator for the Exploration Systems Development Mission Directorate of NASA. Her responsibilities include the development of the Moon to Mars infrastructure, management of systems development for Artemis, and planning NASA's deep space exploration approach. Ms. Koerner previously served as the Deputy Associate Administrator for the directorate and prior to that served as the Orion Program Manager.

Our next witness is Mr. William Russell, Director of Contracting and National Security Acquisitions at GAO (Government Accountability Office). He manages a portfolio which includes issues related to NASA and DOD's (Department of Defense's) industrial base and supply chain integrity, among other topics. Mr. Russell joined GAO in 2002 and has previously served on GAO's Homeland Security and Justice team.

Our third witness is Mr. George Scott, acting Inspector General at NASA. He assumed the role in January of this year, having previously served as the Deputy Inspector General. Prior to joining NASA, Mr. Scott served over three decades at GAO, which included serving as the managing director of GAO's Homeland Security and Justice team.

Our final witness is Dr. Michael Griffin, Co-President of LogiQ, a scientific and technical consulting firm he cofounded. Dr. Griffin previously served as the 11th Administrator of NASA, leading the agency from 2005 to 2009. He has also served as the Under Secretary of Defense for Research and Engineering, as well as the Space Department head at the Johns Hopkins University Applied Physics Laboratory.

Again, thank you all for being here today. And I now recognize Ms. Koerner for five minutes to present her testimony.

**TESTIMONY OF MS. CATHERINE KOERNER,
ASSOCIATE ADMINISTRATOR, EXPLORATION SYSTEMS
DEVELOPMENT MISSION DIRECTORATE,
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION**

Ms. KOERNER. Chairman Lucas, Ranking Member Sorensen, and distinguished Members of the Subcommittee, thank you for the opportunity to testify on NASA's Artemis campaign.

Under the Artemis campaign, the United States, along with our international and commercial partners, will return humans to the Moon to explore, conduct scientific research, and establish the capability for long-term human presence on and around the Moon. Then, using what we learn at the Moon, we will take the next giant leap, sending the first humans to Mars.

In November 2022, NASA took the first major step in America's return to the Moon with the Artemis I mission. That historic launch and 25 1/2-day mission tested the Space Launch System (SLS) rocket, the Orion spacecraft, and the Exploration Ground Systems in preparation for Artemis II. On Artemis II, NASA astronauts Reid Wiseman, Victor Glover, Christina Koch, and Canadian astronaut Jeremy Hansen will journey beyond low Earth orbit and around the Moon, the farthest humans have journeyed into space in more than 50 years.

Approximately one year after Artemis II, the Artemis III crew will land on the lunar south pole and begin building out a robust long-term exploration program. With Artemis IV, astronauts will again visit the lunar surface and start assembly of the space station in lunar orbit called Gateway.

NASA's plan for a successful and sustainable return to the Moon requires the development of several new space systems, including the SLS rocket, the Orion spacecraft, the Exploration Ground Systems, lunar landers, the Gateway space station, and new lunar spacesuits and lunar rovers. Last year, pursuant to the *NASA Authorization Act of 2022,* NASA established the Moon to Mars program office, which focuses on the development of these new systems, mission integration, and risk management across the portfolio. This new office also leads planning and analysis for long-lead technology developments to support humans to Mars.

In the year since NASA's successful Artemis I flight test, NASA has continued to refine the schedule of the follow-on Artemis missions. Based on data from Artemis I and the readiness of the space systems needed to safely transport our crews from Earth to the lunar surface and back, the Artemis II adds several new systems to support astronauts inside of Orion. In addition, we are continuing to study the Orion heat shield from Artemis I to ensure the safety of our crew on future missions. Based on these factors, we're planning for Artemis II to launch in September 2025. Artemis III will build on the progress of Artemis I and II and adds a commercial lunar lander and advanced spacesuits for walking on the lunar surface. In 2026, Artemis III will send humans back to the surface of the Moon.

While sending humans back to the Moon will be a significant accomplishment, we do not intend to stop there. NASA's long-term goal is to send humans to Mars, and the Moon will help us get there. Mars is a rich destination for scientific discovery and a driv-

er of technologies that will enable humans to travel and explore far from Earth. By using what we learn on and around the Moon under Artemis, NASA is working to understand and overcome the future challenges associated with landing and living on Mars.

As NASA builds a blueprint for human exploration throughout the solar system for the benefit of humanity, we conducted our first two architecture concept reviews, the culmination of a robust analysis process designed to align NASA's Moon to Mars exploration strategy and codify the supporting architecture. This annual review is a milestone that enables our Moon to Mars strategy to evolve over time as we consider lessons from previous missions and provide opportunities to onramp new technologies, as well as new industry and international partners.

Through the Artemis campaign, NASA is partnering with the most diverse and broad exploration coalition in history, including multiple international and commercial partners. For example, NASA's Gateway program is an international collaboration with the Canadian Space Agency, European Space Agency, Japan Exploration Agency, and now the United Arab Emirates Mohammed bin Rashid Space Centre to establish humanity's first space station around the Moon. Similarly, NASA is exploring additional international partnerships for lunar surface habitats, logistics, and mobility capabilities that will enable long-term human presence and enhanced scientific returns.

Together, we will continue to develop the technology and the systems needed to live and work on and around the Moon in preparation for human missions to Mars. Because of our diverse astronaut corps, we will be able to fly the first woman, first person of color, and the first international astronaut to the Moon. We will align with our international partners toward a future of expanded economic opportunity and scientific discovery while investing in the next generation of STEM (science, technology, engineering, and mathematics) leaders as we support the limitless possibilities of space exploration.

NASA is grateful for this Committee's continued support of the Artemis campaign, and I appreciate this opportunity to update you on behalf of NASA and our Artemis partners and would be pleased to answer your questions.

[The prepared statement of Ms. Koerner follows:]

National Aeronautics and
Space Administration

Hold for Release Until
Presented by Witness

January 17, 2024

Committee on Science, Space and Technology
Subcommittee on Space and Aeronautics

U.S. House of Representatives

Statement by:

Catherine Koerner, Associate Administrator, Exploration Systems Development Mission Directorate, NASA

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BY WITNESS
January 17, 2024

Statement of

Catherine Koerner
Associate Administrator for Explorations Systems Development Mission Directorate
National Aeronautics and Space Administration

before the

Subcommittee on Space & Aeronautics
House Science, Space & Technology

Chairman Babin, Ranking Member Sorensen and distinguished members of the Subcommittee, thank you for the opportunity to testify on NASA's Artemis program. Under the Artemis program, the United States, along with our international and commercial partners, will return humans to the Moon to explore, conduct scientific research, and establish the capability for a long-term human presence on and around the Moon. Then, using what we learn at the Moon, we will take the next giant leap: sending the first humans to Mars.

In November 2022, NASA took the first major step in America's return to the Moon with the Artemis I mission. That historic launch and 25 and a half-day mission tested the Space Launch System (SLS) rocket, the Orion spacecraft, and the Exploration Ground Systems in preparation for Artemis II. On Artemis II, NASA Astronauts Reid Wiseman, Victor Glover, Christina Koch, and Canadian Astronaut Jeremy Hanson will journey beyond low-Earth orbit and around the Moon – the farthest humans have journeyed into space in more than 50 years. Approximately one year after Artemis II, the Artemis III crew will land at the lunar South Pole and begin building out a robust, long-term lunar exploration program. With Artemis IV, astronauts will again visit the lunar surface and start assembly of a space station in lunar orbit called the Gateway.

NASA's plan for a successful and sustainable return to the Moon requires the development of several new space systems, including the SLS rocket, the Orion spacecraft, the Exploration Ground Systems, lunar landers, the Gateway space station, and new lunar spacesuits and lunar rovers. Last year, pursuant to the NASA Authorization Act of 2022, NASA established the Moon to Mars program office, which focuses on development of these new systems, mission integration, and risk management across the portfolio. This new office also leads planning and analysis for long-lead technology developments to support human Mars missions.

In the year since NASA's successful Artemis I flight test around the Moon, NASA has continued to refine the schedule of the follow-on Artemis missions, based on data from the Artemis I

mission and the readiness of the space systems needed to safely transport our crews from Earth to the lunar surface and back. Artemis II adds several new systems to support astronauts inside Orion. In addition, we are continuing to study the Orion heat shield from Artemis I, to ensure the safety of our crew on future missions. Based on these factors, we are planning for Artemis II to launch in September 2025. Artemis III will build on the progress of Artemis I and II and adds a commercial lunar lander and advanced spacesuits for walking on the lunar surface. In 2026, Artemis III will send humans back to the surface of the Moon.

While sending humans back to the Moon will be a significant accomplishment, we do not intend to stop there. NASA's long-term goal is to send humans to Mars – and the Moon will help us get there. Mars is a rich destination for scientific discovery and a driver of technologies that will enable humans to travel and explore far from Earth. By using what we learn on and around the Moon under Artemis, NASA is working to understand and overcome the future challenges associated with landing and living on Mars. As NASA builds a blueprint for human exploration throughout the solar system for the benefit of humanity, we conducted our first two Architecture Concept Reviews, the culmination of a robust analysis process designed to align NASA's Moon to Mars exploration strategy and codify the supporting architecture. This annual review is a milestone that enables our Moon to Mars strategy to evolve over time as we consider lessons learned from previous missions and provide opportunities to on-ramp new technologies as well as new industry and international partners.

Through the Artemis campaign, NASA is partnering with the most diverse and broadest exploration coalition in history, including multiple international and commercial partners. For example, NASA's Gateway Program is an international collaboration with the Canadian Space Agency, European Space Agency, Japan Aerospace Exploration Agency, and now the United Arab Emirates' Mohammed bin Rashid Space Centre, to establish humanity's first space station around the Moon. Similarly, NASA is exploring additional international partnerships for lunar surface habitats, logistics, and mobility capabilities that will enable long-term human presence and enhanced science returns.

Together, we will continue to develop the technology and systems needed to live and work on and around the Moon in preparation for human missions to Mars. Because of our diverse astronaut corps, we will enable the first woman, the first person of color, and the first international astronaut to walk on the Moon. We will align with partners toward a future of expanded economic opportunity and scientific discovery, while investing in the next generation of STEM leaders as we support the limitless possibilities of space exploration.

NASA is grateful for this committee's continued support of the Artemis program, and I appreciate this opportunity to update you on behalf of NASA and our Artemis partners and would be pleased to answer your questions.

Catherine Koerner

Associate Administrator for Exploration Systems Development

Catherine Koerner is the associate administrator for the Exploration Systems Development Mission Directorate at NASA Headquarters in Washington. She is responsible for the development of NASA's Moon to Mars architecture, defining and managing the systems development for Artemis missions, and planning for integrated deep space exploration approach.

Koerner was formerly the deputy associate administrator for the mission directorate, providing leadership and management of human spaceflight development and operations related to NASA's Moon and Mars exploration goals. She was responsible for establishing and defining future space exploration architectures while overseeing development of new space transportation systems and supporting capabilities that are critical for human-led deep space exploration and scientific research.

Prior to her position at NASA Headquarters, Koerner was NASA's Orion Program manager at NASA's Johnson Space Center in Houston, where she was responsible for oversight of design, development, and testing of the Orion spacecraft. Before leading the Orion Program, Koerner served as the director of Human Health and Performance Directorate, focusing on enhancing crew health and performance and mitigating risks associated with human spaceflight. The core capabilities in the directorate include space and clinical operations; biomedical research and environmental sciences; human systems engineering and development; strategic planning, benchmarking, collaboration, and open innovation.

As a former NASA flight director at NASA Johnson, Koerner led teams in mission control during space shuttle and International Space Station missions. She also previously held several leadership positions within the space station program during its assembly phase and managed NASA's cargo resupply services contracts for it, helping foster a commercial space industry in low Earth orbit. Before joining Johnson in 1991, she worked at NASA's Jet Propulsion Laboratory in Southern California, where her career with the agency began as a mission design engineer.

Koerner earned her Bachelor of Science and Master of Science degrees in aeronautical and astronautical engineering from the University of Illinois at Urbana-Champaign. She has received numerous awards including a Presidential Rank Award in 2019, two Outstanding Leadership Medals (2006, 2013), NASA's Exceptional Service Medal (2007), Johnson's Center Director Commendation (2017) and numerous Group Achievement Awards.

Chairman LUCAS. Thank you very much.

I now recognize Mr. Russell for five minutes to present his testimony.

TESTIMONY OF MR. WILLIAM RUSSELL, DIRECTOR, CONTRACTING AND NATIONAL SECURITY ACQUISITIONS, U.S. GOVERNMENT ACCOUNTABILITY OFFICE

Mr. RUSSELL. Chairman Lucas, Ranking Member Lofgren, Ranking Member Sorensen, Members of the Subcommittee, thank you for the opportunity to discuss NASA's efforts to return astronauts to the surface of the Moon and ultimately human exploration of Mars through the Artemis missions.

NASA has requested at least $38 billion over the next five years to support this ambitious undertaking. The projects supporting Artemis are complex and specialized and often push the state-of-the-art in space technology. These new projects include a Human Landing System (HLS) to transport crew to the lunar surface and spacesuits for lunar operations. In addition, NASA plans to rely on existing programs, including the Orion multipurpose crew vehicle and the Space Launch System. Successfully executing the Artemis missions will require extensive coordination across programs and with a wide range of contractors to ensure systems operate together seamlessly and safely.

Our work has highlighted NASA's progress toward its Artemis flight tests and lunar landing mission. Examples include the successful launch of Artemis I in November 2022, which demonstrated the initial capability of the Space Launch System, as well as the Exploration Ground Systems. For Artemis II, the first flight with crew, NASA is currently conducting integration and testing of the crew capsule and the launch pad. And for Artemis III, the first crewed lunar landing mission, the HLS contractor has conducted two test flights. NASA also continues to make progress on its integration and risk management plans, such as establishing mechanisms for identifying and tracking Artemis III risks and the establishment and implementation of the Moon to Mars program office.

While NASA continues to develop capabilities needed to support Artemis efforts, the agency does face several challenges. These include the Artemis schedule, a lack of transparency into the Artemis mission and program costs, and other acquisition management challenges. In terms of Artemis III's schedule, in our November 2023 report, we found that there were a variety of factors that made the previous December 2025 date unlikely. These included an ambitious schedule, delays to key events, and the remaining technical work. Specifically, we found that if the HLS development took as many months to complete as an average NASA project, it was likely Artemis III would be likely to occur in early 2027. Just last week, NASA adjusted the launch date to September 2026 to allow contractors more time to complete a significant amount of remaining technical work.

In terms of Artemis III mission costs, in December 2019 we found that NASA didn't plan to establish an official cost estimate for this mission. We made a recommendation, and NASA concurred with it, to establish one but has not yet done so. While NASA requested $6.8 billion to support Artemis III programs in the Fiscal

Year 2024 budget request, decisionmakers will have limited knowledge into the full scope of the Artemis III mission costs until an estimate is created.

Last, in terms of acquisition management, NASA has been on GAO's high risk list for a number of years related to acquisition management and has made a lot of progress there, but NASA's largest, most complex projects, including those that support the Artemis missions, continue to shape the agency's entire acquisition portfolio. When these projects exceed their cost or schedule baselines, it can have cascading effects on other projects and efforts. In our '23 assessment of NASA projects, we found that NASA anticipated setting baselines for six Artemis programs, including HLS. As these projects enter the portfolio, they will drive the agency's acquisition performance over the next several years for good or ill.

In summary, NASA's made important progress on its Artemis efforts, but challenges remain. NASA will need to manage multiple risks seamlessly. It will need to continue to find ways to elevate risks across programs and mitigate those. That includes increasing transparency on how much Artemis III and future Artemis missions are likely to cost. Implementing our past recommendations will help NASA to improve in these critical areas.

Chairman Lucas, this completes my prepared remarks. I look forward to any questions the Subcommittee may have.

[The prepared statement of Mr. Russell follows:]

United States Government Accountability Office

Testimony

Before the Subcommittee on Space and Aeronautics, Committee on Science, Space, and Technology, House of Representatives

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NASA ARTEMIS PROGRAMS

Lunar Landing Plans Are Progressing, but Challenges Remain

Statement of William Russell, Director, Contracting and National Security Acquisitions

GAO-24-107249

GAO Highlights

Highlights of GAO-24-107249, a testimony before the Subcommittee on Space and Aeronautics, Committee on Science, Space, and Technology, House of Representatives

Why GAO Did This Study

The National Aeronautics and Space Administration (NASA) is committing billions of dollars to return humans to the lunar surface and initiate human exploration of Mars. The missions, known collectively as Artemis, involve the development and integration of multiple systems and programs.

This testimony focuses on NASA's progress toward achieving the Artemis missions, as well as the challenges the agency faces in conducting them. This statement is based on past GAO reports on the Artemis enterprise and our annual assessment of NASA's major projects.

What GAO Recommends

GAO has made numerous recommendations to reduce NASA's acquisition risk and improve NASA's management of its portfolio of major projects, which includes projects supporting the Artemis missions. NASA has generally agreed with the recommendations and implemented changes in response to many of them. However, it needs to take additional actions to fully address all of them.

As of May 2023, GAO identified six open recommendations related to Artemis as being a priority for implementation. For example, NASA concurred with our December 2019 recommendation to create a life-cycle cost estimate for the Artemis III mission but has not yet implemented it.

View GAO-24-107249. For more information, contact William Russell at (202) 512-4841 or russellw@gao.gov.

January 17, 2024

NASA ARTEMIS PROGRAMS

Lunar Landing Plans are Progressing but Challenges Remain

What GAO Found

NASA has made progress demonstrating key capabilities needed to support its Artemis missions:

- **Artemis I**, an uncrewed test flight, successfully launched in November 2022, which demonstrated the initial capability of the Space Launch System and Exploration Ground Systems.
- For **Artemis II**, the first flight with crew, NASA is currently conducting integration and testing of the crew capsule and the launch pad.
- NASA and its contractors continue to make progress on technologies supporting **Artemis III**, the first crewed lunar landing mission. For example, the human landing system contractor has conducted two test flights of its human landing system.

Notional Depiction of the Human Landing System

Source: SpaceX. | GAO-24-107249

Despite this progress, NASA still faces several challenges:

- **Ambitious schedules**. In November 2023 (GAO-24-106256), GAO found that the Artemis III lunar landing was unlikely to occur in December 2025, as planned, given delays and remaining technical work. In January 2024, NASA adjusted the launch date to September 2026 to allow contractors time to complete a significant amount of remaining complex work.
- **Artemis III mission cost**. In December 2019 (GAO-20-68), GAO found that NASA did not plan to establish an official cost estimate for this mission. NASA concurred with a GAO recommendation to establish one but has not yet done so. While NASA requested $6.8 billion to support Artemis III programs in its fiscal year 2024 budget request, decision-makers have limited knowledge into the full scope of Artemis III mission costs.
- **Acquisition management**. NASA's largest, most complex projects, including those that support the Artemis missions, continue to shape the agency's portfolio. When these projects exceed their cost baselines and require cost reserves to meet their funding needs, it has a cascading effect on other projects. NASA officials are exploring ways to better manage this project cost and schedule growth.

January 17, 2024

Chairman Babin, Ranking Member Sorensen, and Members of the Subcommittee:

Thank you for the opportunity to discuss the National Aeronautics and Space Administration's (NASA) efforts to return astronauts to the surface of the moon and, ultimately achieve human exploration of Mars. In the fiscal year 2024 President's budget request, NASA requested at least $38 billion over the next 5 years to support this ambitious undertaking, known collectively as the Artemis missions. The projects supporting the Artemis missions are complex and specialized, and often push the state of the art in space technology. Executing Artemis missions will require extensive coordination across several NASA programs to ensure systems operate together seamlessly and safely. The Artemis missions will also partner with contractors to develop, demonstrate, and produce critical components as part of a strategy to leverage commercial investment and interest in space technology.

We previously highlighted NASA's progress toward achieving the lunar landing mission, such as establishing integration processes and completing some lunar program development activities. We also reported on the challenges NASA faces in developing and integrating these systems and missions.[1] Improving acquisition management—which has been a long-standing challenge at NASA—will play a key role in successfully executing the Artemis enterprise.[2]

You asked us to testify today on our work examining NASA's lunar programs. My statement focuses on (1) progress NASA has made on its Artemis missions, and (2) challenges the agency faces in conducting these missions.

This statement is based on our previously issued reports on NASA's Artemis efforts, including reports that focus on the lunar programs necessary to support the Artemis III missions and our annual assessment of NASA's major projects. We also compared original Artemis mission

[1]GAO, *NASA Lunar Programs: Improved Mission Guidance Needed as Artemis Complexity Grows*, GAO-22-105323 (Washington, D.C.: Sept. 8, 2022); and *NASA Artemis Programs: Crewed Moon Landing Faces Multiple Challenges*, GAO-24-106256 (Washington, D.C.: Nov. 30, 2023).

[2]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).

dates from previously obtained NASA documentation to the new dates announced by NASA in January 2024 to determine any delays. The reports cited throughout this statement include detailed information on their scope and methodology.

We conducted the work on which this statement is based 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

Key Elements of NASA's Planned Return to the Moon

The goal of NASA's Artemis enterprise is to return U.S. astronauts to the surface of the moon, establish a sustained lunar presence, and, ultimately, achieve human exploration of Mars. To do so, NASA programs are developing multiple highly complex and interdependent systems that will need to be integrated to support individual Artemis missions.

- The Artemis I and II missions are the first uncrewed and crewed demonstration missions, respectively, of the Space Launch System (SLS) launch vehicle, the Orion Multi-Purpose Crew Vehicle (Orion), and the associated ground systems, known as Exploration Ground Systems (EGS).
- The Artemis III mission will leverage contracts with commercial companies to develop the human landing system (HLS) and space suits. NASA awarded firm-fixed-price indefinite delivery, indefinite quantity contracts to two companies, SpaceX and Axiom Space, to develop these capabilities.[3]
  - SpaceX is developing the HLS, which will provide crew access to the lunar surface and demonstrate initial capabilities required for deep space missions.
  - Axiom Space is developing modernized space suits, which consist of a combination of a pressure garment and life support

[3]NASA also awarded a task order to Collins Aerospace to begin development activities on a space suit capability for Artemis III. However, we did not include these activities in our work upon which this statement is based.

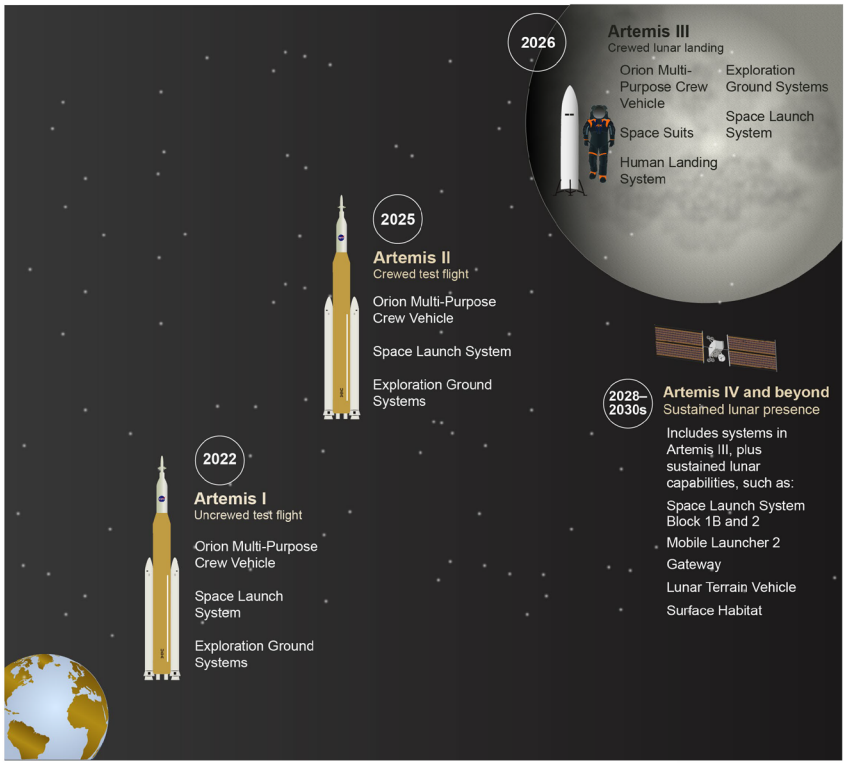
components that together will provide capacity for at least 8 hours of lunar surface activity.

- The Artemis IV and later missions plan to focus on establishing a sustainable lunar presence. For example, NASA is developing a lunar orbiting outpost—called the Gateway—as a habitat and safe work environment for astronauts. NASA also plans to use the SLS Block 1B and Mobile Launcher 2, which will provide additional capability in these later missions.
- NASA stated that later missions on and around the moon will help prepare for the types of mission durations and operations it will experience on human missions to Mars.[4]

See figure 1 for the programs needed to accomplish the Artemis missions.

[4]NASA, *Artemis Plan: NASA's Lunar Exploration Program Overview* (September 2020).

Figure 1: Key NASA Programs Supporting Artemis Missions



Source: GAO presentation of NASA documentation. | GAO-24-107249

NASA Public-Private Partnerships

NASA has expanded its effort to contract with commercial companies, especially for its human spaceflight efforts. For example, NASA established the Commercial Crew and Cargo Program Office in 2005 to encourage the growth of the private spaceflight sector in the U.S. According to NASA, the public-private partnerships established by this program office represented a new way of doing business in the realm of human spaceflight.

NASA has continued to build on this experience to support the Artemis missions to return humans to the lunar surface. For example:

- The HLS program is using commercial partnerships to develop and jointly deploy a landing system to transport humans to and from the lunar surface. NASA expects that its commercial partners will heavily leverage NASA technology and expertise throughout the development process, leading to a lunar transportation system that will deliver humans to the lunar surface. NASA also expects that its commercial partners will develop and demonstrate a more sustainable HLS for subsequent crewed missions. In July 2021, NASA exercised a $2.9 billion option on its contract with SpaceX to provide crew access to the lunar surface and demonstrate initial capabilities for deep space missions.[5]
- NASA's Extravehicular Activity (EVA) Development project, which oversees space suit development, is also using commercial partnerships to develop a modernized space suit and associated hardware for lunar surface exploration. In May 2022, NASA awarded firm-fixed-price indefinite delivery, indefinite quantity contracts to Axiom Space and Collins Aerospace. These companies are to provide safe and reliable commercial extra-vehicular activities in microgravity and partial gravity environments on the International Space Station and the lunar surface for Artemis missions.[6] In September 2022,

[5]NASA first awarded the HLS contract to three providers in May 2020. In April 2021, NASA announced the selection of SpaceX for the award of the contract to develop the Artemis III human landing system. After the award, Blue Origin and Dynetics filed bid protests with GAO, which GAO denied in July 2021. GAO, *Blue Origin Federation, LLC; Dynetics, Inc.-A Leidos Company,* B-419783; B-419783.2; B-419783.3; B-419783.4, July 30, 2021, 2021 ¶ CPD 265 (Washington, D.C.: July 30, 2021). Subsequently, in August 2021, Blue Origin filed a complaint with the U.S. Federal Court of Claims. The court dismissed this complaint in November 2021. Blue Origin Fed. LLC v. United States, Fed. Cl., No. 21-1695C (Nov. 4, 2021).

[6]An indefinite delivery, indefinite quantity contract provides for an indefinite quantity, within stated limits, of supplies or services during a fixed period. The government places orders for individual requirements. FAR 16.504(a).

NASA issued a $229 million order under Axiom's contract for the development and demonstration of a suit for lunar surface activities. Axiom is required to provide space suits that will allow crew to successfully perform exploration and science missions on the lunar surface during the Artemis III mission.

NASA Continues to Make Progress Demonstrating Capabilities Needed for the Lunar Landing Mission

Since we reported on the status of the Artemis missions and programs in March 2022, NASA has demonstrated a number of initial capabilities needed to support the lunar landing mission.[7] Examples of key events include the following:

- **Artemis I** successfully launched on November 16, 2022, with the Orion capsule safely returning to Earth on December 11, 2022. SLS and EGS demonstrated their initial capabilities during this first test flight.
- **Artemis II** integration and testing with the Orion crew capsule is ongoing. In October 2023, NASA joined together the Orion crew module and service module. Now that the crew and service modules are integrated, the team will power up the combined crew and service module for the first time. After power on tests are complete, Orion will begin altitude chamber testing, which will put the spacecraft through conditions as close as possible to the environment it will experience in the vacuum of deep space.

  NASA plans to conduct several key integration and test events, for example, ground system testing of the new launch pad systems. Teams will conduct a variety of tests and continue ground systems upgrades. These preparations include testing the pad's emergency egress system. After testing at the pad is complete, the mobile launcher will travel to the Vehicle Assembly Building in preparation for rocket stacking operations ahead of launching Artemis II.
- NASA continues to make progress on its integration and risk management plans for the **Artemis III** mission. In September 2022, we found that NASA had established several mechanisms for identifying and tracking Artemis III risks—including a risk database, scorecard, and cross-program risk reviews—and had begun implementing them.[8]

[7]GAO, *NASA Lunar Programs: Moon Landing Plans Are Advancing but Challenges Remain*, GAO-22-105533 (Washington, D.C.: Mar. 1, 2022).

[8]GAO-22-105323.

Further, in November 2023, we found that NASA had made progress completing several important milestones with contractors to develop the HLS and space suits needed to support the Artemis III mission.[9]

- NASA and SpaceX completed several important milestones and made progress in designing and testing components of the HLS Starship. SpaceX is currently developing a commercial Starship vehicle to transport humans and cargo to low-Earth orbit, the moon, and Mars. The HLS Starship system consists of the SpaceX Super Heavy booster (launch vehicle) and HLS Starship (the vehicle that provides crew access to the lunar surface). SpaceX is also developing a propellant tanker and on-orbit propellant depot for its lunar landing mission concept.

  Additionally, SpaceX conducted launches of its commercial Starship in April and November 2023. The two test flights provided SpaceX with early in-flight data on the engines, vehicle tanks, and primary structures, among other things. These test flights are important steps towards eventually testing the lander's propellant transfer capabilities in space. We found that these were key development tests for achieving the planned crewed landing.

- Axiom made progress in developing the space suits by completing several milestones, including the mission concept review in December 2022 and the Certification Baseline Review in March 2023. To deliver and demonstrate lunar surface space suits and associated systems, Axiom is leveraging many aspects of NASA's previously developed design. According to Axiom representatives, they entered preliminary design review in September 2023 and completed the crew capability assessment.

NASA Faces Challenges Related to Artemis Schedule, Cost, and Acquisition Management

While NASA continues to develop capabilities needed to support its Artemis efforts, the agency faces several challenges. These include an ambitious Artemis III schedule, a lack of transparency into Artemis mission and program costs, and other acquisition management challenges.

[9]GAO-24-106256.

Updated Artemis III Mission Time Frames Acknowledge Remaining Work

In January 2024, NASA announced new mission dates. It shifted Artemis II from the most recent estimate of November 2024 to September 2025 and Artemis III from the most recent estimate of December 2025 to September 2026. NASA officials stated that this shift will allow additional time to complete testing and remaining technical work. The revised NASA estimates show a 2-year delay from the original launch dates for the Artemis II and Artemis III missions. Table 1 depicts the changes to the planned mission dates.

Table 1: Original and Planned Dates for First Three Artemis Missions as of January 2024

Artemis mission	Originally planned launch date	Current planned launch date
Artemis I	November 2018	Successfully launched November 2022
Artemis II	April 2023	September 2025
Artemis III	September 2024	September 2026

Source: GAO analysis of NASA documentation. | GAO-24-107249

In our November 2023 report, we found that a variety of factors made the previous December 2025 lunar landing date unlikely.[10] These factors included an ambitious schedule, delays to key events, and remaining technical work. Specifically, we found that, if the HLS development takes as many months as NASA major projects do on average, the Artemis III mission would likely occur in January 2027. Our analysis found that past NASA projects that have launched since 2010 took 92 months from project start to launch, while NASA's planned development time for the HLS was 79 months. Additionally, we found that the HLS program and SpaceX had delayed eight out of 13 key events by between 6 and 13 months. According to NASA, the updated mission time frames will allow SpaceX and Axiom additional time for testing and refinements ahead of the Artemis III mission.

The HLS and Extravehicular Activity and Human Surface Mobility programs will need to complete a significant amount of complex technical work to achieve the planned September 2026 lunar landing goal. For example, SpaceX has remaining development work on both the Raptor engine and on-orbit propellant transfer technology to mature them. Likewise, Axiom has significant work to complete, including maturing critical technologies for the space suit life support system, procuring suit

[10]GAO-24-106256.

components that are susceptible to supply chain delays, and qualifying the suit for flight.

Mission and Program Costs Are Not Transparent

To date, NASA has not yet prepared an estimate of how much the Artemis III mission—or subsequent Artemis missions—are likely to cost. Similarly, it does not plan to measure the production costs for the SLS rockets that constitute a significant proportion of future Artemis-related costs. As such, decisionmakers will have limited information available to help inform decisions on the overall lunar investment.

- **Artemis III mission costs**. In December 2019, we found that NASA estimated that Artemis III may cost between $20 billion and $30 billion, but the agency did not plan to establish an official cost estimate.[11] At that time, we recommended that it do so. NASA agreed with the recommendation and indicated it would provide a preliminary cost estimate for the Artemis III mission by the end of calendar year 2020. NASA did not do so at that time. Subsequently, in February 2023, NASA officials stated that they are developing a methodology to provide Congress with an assessment of costs for each Artemis mission. NASA officials stated that the mission estimates will include the cost of hardware production, integration costs, and operations costs, but did they not provide a time frame for when this would be completed. Implementing our previous recommendations to develop a life-cycle cost estimate for the Artemis III mission as a whole will enable NASA to effectively monitor total mission costs and give Congress valuable insight into mission affordability when making decisions about each year's budget.
- **SLS production costs**. In September 2023, we found that NASA does not plan to measure production costs for the SLS program.[12] Since SLS's first launch for Artemis I in November 2022, NASA plans to spend billions of dollars to continue producing multiple SLS components—such as core stages and rocket engines—needed for future Artemis missions. These ongoing production costs are not captured in a cost baseline, which limits transparency and efforts to monitor the program's long-term affordability. This is important because the production and other costs for the SLS program account for more than one-third of NASA's budget request for programs required to return to the moon. For example, in the President's budget

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

[12]GAO, *Space Launch System: Cost Transparency Needed to Monitor Program Affordability*, GAO-23-105609 (Washington, D.C.: Sep 7, 2023).

submission for fiscal year 2024, NASA requested $6.8 billion for the five programs that will be required for Artemis III. The SLS program accounted for about $2.5 billion, or 37 percent of that request. Implementing our prior recommendations to establish cost and schedule baselines that capture these ongoing, recurring production costs could improve transparency into the program.

Acquisition Management Challenges

NASA has made improvements to its acquisition management policies and practices—a long-standing challenge at NASA—in recent years. 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. Several of the key improvements we have reported on since March 2022 include the following examples:

- In our June 2022 report, we found that the agency institutionalized some strategic, senior-level reviews to understand and address the ongoing risks that its portfolio may face.[13] For example, the agency holds monthly reviews chaired by the NASA Associate Administrator to discuss issues requiring leadership awareness and identify solutions to challenges as they arise. NASA officials told us that senior management periodically assesses mission directorate portfolios, focusing on Category 1 and other highly visible programs and projects during these meetings.[14]
- In August 2022, NASA updated its corrective action plan as part of its efforts to address recent programmatic performance and its inclusion in our biennial High-Risk Report.[15] The plan describes a number of actions the agency intends to take to improve acquisition and program management.
- In our April 2023 High-Risk Update, we found that NASA completed several initiatives to strengthen its cost and schedule estimating capacity and is embracing tools to support better management practices.[16] We noted, however, that NASA will need to identify ways

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

[14]Projects designated as Category 1 are NASA's highest priority projects and generally have life-cycle costs over $2 billion.

[15]GAO-23-106203.

[16]GAO-23-106203.

to improve its management of Category 1 projects to continue reducing acquisition risk and demonstrating progress.

These Category 1 projects drive cumulative cost performance for the entire portfolio when they overrun their baselines. In our 2023 assessment of major NASA projects, we found that NASA anticipated setting baselines for six Artemis programs.[17] As these projects enter the portfolio, they will drive the agency's acquisition performance over the next several years. NASA senior leaders said that recent efforts intended to help control project cost and schedule growth include having projects (1) document when they deviate from the agency's policy for establishing cost and schedule baselines and (2) develop plans to remove work if cost growth or schedule delays occur. These officials said they plan to explore additional ways to control project costs and schedules, specifically for Category 1 projects.

In summary, NASA has made important progress on its Artemis efforts, but completing the lunar landing mission remains challenging. NASA needs to continue to find ways to better manage the cost of its most complex programs. Further, NASA has not yet determined how much Artemis III and future Artemis missions are likely to cost, limiting critical information needed by decision-makers about the lunar mission. Implementing our past recommendations will help NASA to improve in these critical areas.

Chairman Babin, Ranking Member Sorensen, and Members of the Subcommittee, this completes my prepared statement. I would be pleased to respond to any questions that you may have at this time.

GAO Contact and Staff Acknowledgments

If you or your staff have any questions about this testimony, please contact William Russell, Director, CNSA at (202) 512-4841or russellw@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this statement.

GAO staff who made key contributions to this testimony are Kristin Van Wychen (Assistant Director); Erin Roosa (Analyst-in-Charge); John Armstrong; Breanne Cave; Edward Harmon; Tonya Humiston; Erin

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

Kennedy; John Ortiz; Sylvia Schatz; Kate Sharkey; Juli Steinhouse; Kevin Walsh; Alyssa Weir; and Tonya Woodbury.

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William joined GAO in 2002 and has served as Acting Director in GAO's Homeland Security and Justice team, managing a portfolio of issues related to aviation security, surface transportation security, and DHS research and development.

William earned a master's degree in foreign affairs from the University of Virginia and a bachelor's degree in political science from Virginia Commonwealth University.

Chairman LUCAS. Thank you. I now recognize Mr. Scott for five minutes to present his testimony.

TESTIMONY OF MR. GEORGE A. SCOTT,

ACTING INSPECTOR GENERAL,

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. SCOTT. Good morning. Chairman Lucas, Ranking Member Lofgren, Ranking Member Sorensen, and Members of the Subcommittee, thank you for inviting me here today to discuss key challenges facing NASA's Artemis campaign. At the outset, I would like to thank the Subcommittee for your continued support of our oversight work.

Also, I would like to thank Paul Martin, our former Inspector General, for his exceptional leadership of our office over the past 14 years. It was a pleasure serving as his deputy for the last 5 1/2 years.

Historically, NASA has struggled to establish credible cost and schedule estimates, and Artemis is no exception. After more than a decade of preparation and delays, NASA successfully completed the Artemis I mission in December of 2022. Despite this achievement, NASA faces additional challenges to meeting its Artemis goals. Of utmost importance is resolving technical issues that could threaten astronaut safety. The agency will need to do this while also addressing longstanding concerns such as unsustainable costs, unreliable project schedules, and the lack of transparency into funding needs.

In terms of technical challenges, NASA's most immediate issue is preparing for the Artemis II mission, the first crewed test flight of SLS and Orion. For example, the Artemis I flight revealed unexpected erosion of protective material on Orion's heat shield. In addition, the agency has identified other issues with Orion that it needs to correct before the next launch.

Recognizing the challenges that lie ahead, last week, NASA announced delays to the next two Artemis missions. This will allow more time to address technical issues identified during the first mission, as well as support for the development and testing of other systems, including the Human Landing System and next-generation spacesuits.

The second challenge is the campaign's enormous cost. Overall, we projected that total Artemis costs will reach $93 billion between 2012 and 2025. We also estimate that SLS and Orion production and operating costs will total at least $4.2 billion per launch for the first four Artemis missions. This figure does not include $42 billion in formulation and development costs spent over the past dozen years.

Given these costs, it is imperative that NASA identify and effectively implement cost-saving measures. To its credit, the agency recognizes the need to reduce costs and is attempting to do so. Our work, however, has found that some key cost reduction efforts may fall short. This is due in part to NASA not capturing certain costs when developing estimates or relying on unrealistic assumptions. NASA also wants to make its Moon to Mars effort more sustainable by sharing costs with its international partners. However, the

agency current plans—the agency's current plan does not include cost estimates for these partners beyond Artemis IV.

Finally, the Artemis campaign lacks cost and schedule transparency. NASA has not developed a comprehensive estimate for all Artemis costs. And, unlike its other major projects and programs, NASA has not established lifecycle costs or made cost and schedule commitments for some programs supporting Artemis. Without the agency fully accounting for and accurately reporting the overall cost of current and future missions, it will be difficult for Congress to make informed decisions about NASA's long-term funding needs. Further, without credible, complete, and transparent costs and schedule estimates, NASA will be hard pressed to achieve meaningful cost savings, a key step to making Artemis truly sustainable over time.

We look forward to assisting NASA in achieving its Artemis goals and will continue to provide independent, objective, and comprehensive oversight of this effort. Thank you.

[The prepared statement of Mr. Scott follows:]

NASA
National Aeronautics and Space Administration

Office of Inspector General

Testimony before the House of Representatives
Subcommittee on Space and Aeronautics,
Committee on Science, Space, and Technology

KEY CHALLENGES FACING NASA'S ARTEMIS CAMPAIGN

Statement of George A. Scott
Acting Inspector General
National Aeronautics and Space Administration

For Release on Delivery (expected at 10 a.m.)
January 17, 2024

Chairman Babin, Ranking Member Sorensen, and Members of the Subcommittee:

Our mission is to provide independent, objective, and comprehensive oversight of NASA's programs and projects to help ensure that the Agency operates with transparency, efficiency, and accountability. As part of this mission, we provide oversight on significant challenges facing NASA and impacting the Artemis campaign.

After more than a decade of preparation and several delays, in December 2022 NASA successfully completed Artemis I—an uncrewed test flight to lunar orbit. Artemis I was a significant achievement for NASA, providing important data and lessons learned from the testing of hardware, software, processes, and teams that will help prepare NASA for future Artemis missions. Despite this achievement, our oversight has identified several interrelated challenges NASA must address to achieve its ambitious Artemis goals. Of utmost importance is the resolution of technical challenges that could threaten astronaut safety while also addressing historical challenges related to unsustainable costs and a lack of transparency into funding needs.

First, the Artemis campaign's technical challenges. The Agency's immediate challenge is preparing for Artemis II—the first crewed test flight of the Space Launch System (SLS) heavy-lift rocket and Orion Multi-Purpose Crew Vehicle (Orion) system—which will return humans to lunar orbit for the first time in more than 50 years. The Agency continues to analyze mission data from Artemis I and must address a variety of technical challenges to safely fly four astronauts to lunar orbit on their planned 10-day Artemis II mission. While considered a near-perfect flight by NASA officials, Artemis I revealed technical issues such as the unexpected erosion of protective material on the Orion heat shield. In addition, the Mobile Launcher 1 platform—the ground structure used to assemble, process, transport, and launch the SLS for Artemis I through III—sustained more damage than expected. Just last week, NASA delayed the Artemis II mission to September 2025.

Looking ahead to Artemis III—the mission that will return humans to the surface of the Moon—NASA's commercial partner SpaceX must conduct multiple flight tests and launches of its Human Landing System (HLS) Starship before using its lander variant with astronauts onboard. The HLS requires SpaceX to launch a series of Starship vehicles to establish a "fuel depot" in low Earth orbit to refuel each Starship heading to the Moon. Moreover, under its contract with NASA the company is required to send an uncrewed Starship to the lunar surface and back prior to Artemis III to demonstrate its readiness for a crewed mission. At the same time, NASA must develop additional capabilities including next-generation spacesuits. With last week's announcement, NASA also delayed Artemis III to September 2026 in part to provide additional time to develop SpaceX's HLS Starship and next-generation spacesuits.

For missions beyond Artemis III, the second mobile launcher (ML-2) is a critical part of the infrastructure needed to launch the upgraded SLS Block 1B and Block 2. In June 2022, we reported that the ML-2 project is significantly behind schedule and over budget, jeopardizing launch schedules for Artemis IV and beyond. While the ML-2's first steel components were delivered to Kennedy Space Center in May 2023, we estimate completion of the launcher will not occur until late 2026 at the earliest, 2.5 years behind the project's originally scheduled date.

The second challenge is the Artemis campaign's enormous expense. Overall, we project NASA's total Artemis campaign costs to reach $93 billion between fiscal years 2012 and 2025. We also project the SLS/Orion system and related ground launch infrastructure will cost at least $4.2 billion per launch for the first four Artemis missions, a figure that does not include $42 billion in formulation and development costs spent over the past dozen years to bring these systems to the launch pad.

Development of the systems required to transport humans to the Moon and Mars safely has proven to be especially challenging due to increased costs stemming from significant technical issues, changing requirements, and overly optimistic schedules.

Given these estimated costs and the significant challenge they pose to the long-term sustainability of the Artemis campaign, it is critical that the Agency identify and implement effective ways to reduce costs. This will be especially important as Congress urges NASA to increase the SLS/Orion launch cadence at the same time NASA—and much of the federal government—may be operating under a flat annual budget. Our recent work has shown that some key cost reduction efforts may fall short of expectations.

For example, in May 2023 we reported that NASA is projecting manufacturing cost savings of 30 percent per engine for the SLS starting with production of the seventh of 24 new RS-25 engines. However, these projected savings do not capture overhead and other costs associated with restarting production of the engine, which we estimated to reach $2.3 billion. Likewise, in October 2023 we reported on NASA's efforts to reduce the cost of lunar missions beyond Artemis IV by transitioning management of multiple contractors for production of SLS systems and hardware, as well as systems integration and launch services, to a single contractor service. We found this approach would likely not achieve its cost reduction goals due to a variety of unrealistic assumptions, such as finding customers outside of NASA to use the SLS. Additionally, NASA aims to make its Moon to Mars plan more sustainable by sharing costs with its international partners. However, we found NASA's cost-sharing strategies with its international partners are still evolving and the Agency lacks an overall architecture, or blueprint, that includes cost estimates and responsibilities for international partners beyond Artemis IV.

The final challenge we highlight today is the Artemis campaign's lack of cost and schedule transparency. In particular, NASA still lacks a comprehensive and accurate estimate that accounts for all Artemis costs. For example, we previously reported that NASA had neither established life-cycle costs nor made cost and schedule commitments for some of the programs supporting the Artemis campaign. By failing to do so, the Agency is circumventing congressional requirements for reporting and tracking such costs. We continue to believe the Agency needs to provide full visibility into its investments as it begins a multi-decade Moon to Mars initiative at a cost that could easily reach into the hundreds of billions of dollars. As the programs that support these exploration missions transition from development to production and operation, it is critical that NASA establish credible, complete, and transparent cost and schedule estimates from which they can measure success and be accountable to Congress and other stakeholders.

Over the past two years, the OIG has issued nine audit reports that examine issues critical to NASA's effort to land humans on the Moon as a prelude to a crewed Mars mission. We assessed NASA's transition of the SLS to a commercial services contract, the Artemis supply chain, communication infrastructure, SLS engine and booster contracts, partnerships with international space agencies, ground systems and launch infrastructure, cost estimating and reporting practices, management of the Agency's astronaut corps, and management of the Artemis missions. Below, we summarize these reports, findings, and recommendations.

NASA's Transition of the Space Launch System to a Commercial Services Contract (IG-24-001, October 2023)

In an effort to increase the affordability of the Artemis campaign, NASA is preparing to award a sole-sourced services contract, known as the Exploration Production and Operations Contract (EPOC), to Deep Space Transport, LLC (DST)—a newly formed joint venture of The Boeing Company and Northrop

Grumman Systems Corporation—for the production, systems integration, and launch of at least 5 and up to 10 SLS flights beginning with Artemis V scheduled for 2029.

We found that despite NASA's noteworthy adjustments to the EPOC transition plan and its affordability initiatives, the price of the SLS Block 1B rockets will not be significantly reduced through a sole-source contract with DST. NASA's aspirational goal is to achieve a 50 percent cost savings over current SLS production costs using DST, which by our calculation would reduce the contract cost of a single SLS rocket from $2.5 billion to $1.25 billion. Our analysis shows this goal cannot be achieved and the production cost alone will remain over $2 billion. We reach this conclusion after examining what we believe are unrealistic assumptions on NASA's part. First, the Agency expects to achieve cost savings through reduced SLS production costs under a contract with DST. However, ongoing affordability efforts by SLS contractors to reduce the workforce and improve manufacturing processes have yet to achieve cost savings on the high-cost stages and RS-25 engine contracts. Second, DST expects to drive down costs by increasing the SLS production rate and building more SLSs for non-NASA customers such as the Department of Defense and commercial entities. However, thus far other potential users have declined to use the SLS due to lower-cost alternatives. Finally, NASA's ability to negotiate less costly services with DST will be hindered by the lack of competition given EPOC is sole sourced to the existing SLS contractors.

The OIG made seven recommendations to improve the sustainability of the SLS system.

NASA's Management of the Artemis Supply Chain (IG-24-003, October 2023)

Each of NASA's Artemis-related programs rely on specialized parts supplied by contractors and subcontractors from across the United States and around the world. NASA's contractors employ a network of subcontractors and suppliers to provide the hardware, raw materials, electronic parts, and other resources needed to fulfill their contracts. To support the Artemis campaign, NASA obligated approximately $40 billion to 860 contractors from fiscal years 2012 to 2022.

We found that NASA and its prime contractors continue to experience challenges obtaining key components and necessary supplies to meet Artemis goals resulting in cost increases and schedule delays. Supply chain delays and disruptions over the past several years have resulted from a variety of factors outside the Agency's control, from the COVID-19 pandemic to inflation of wages and material costs to the Russia-Ukraine conflict. That said, several factors related to managing Artemis supply chain issues are within NASA's purview. Most importantly, this includes the Agency's lack of visibility into its critical suppliers, with many Artemis programs and projects not tracking their prime contractors' supply chain impacts. Even when issues with subcontractors and suppliers are identified, performance challenges are not shared across Artemis programs to enable effective procurement decisions. To its credit, NASA is undertaking efforts to better understand supply chain issues and manage them more proactively, but these initiatives are still in the early stages.

The OIG made seven recommendations to improve NASA's management and visibility into its supply chain.

Audit of NASA's Deep Space Network (IG-23-016, July 2023)

NASA relies on its Deep Space Network (DSN) to provide communication links that guide and control spacecraft such as the Orion and bring back images and other data from missions such as the James

Webb Space Telescope. The DSN consists of three communications facilities in the United States, Spain, and Australia that use antennas to communicate with spacecraft located between 10,000 miles from Earth to beyond the edge of the solar system.

We found DSN antennas are operating at capacity and are oversubscribed—meaning more time is requested by missions than the network's current capacity can provide—with demand exceeding supply at times by as much as 40 percent. The Agency's crewed Artemis missions to the Moon will require increasingly higher amounts of bandwidth and further constrict the network's ability to meet growing mission demands. As NASA pivots toward extended human exploration of the Moon, the Agency may need to give DSN capacity to priority missions in critical phases, such as launches, while other missions make do with limited or no data during those periods. NASA's primary solution to address the DSN's capacity issues is to construct additional antennas and make upgrades to existing infrastructure. However, these efforts are behind schedule and over budget, experiencing nearly 5 years of delays, only partial completion of two phases of construction, and an expected 68 percent cost increase.

The OIG made four recommendations to ensure NASA's progress towards upgrading the Agency's DSN and the network's ability to support current and future mission requirements.

NASA's Management of the Space Launch System Booster and Engine Contracts (IG-23-015, May 2023)

Key to NASA's Artemis campaign is development of the SLS—a two-stage, heavy-lift rocket with two boosters and four RS-25 engines that will launch the Orion into space. From fiscal years 2012 through 2025, NASA's overall Artemis investment is projected to reach $93 billion, of which the SLS Program costs represent $23.8 billion spent through 2022. This audit examined two SLS booster contracts with Northrop Grumman and two RS-25 engine contracts with Aerojet Rocketdyne. We found that NASA is experiencing significant scope growth on both contracts, as well as approximately $6 billion in cost increases and over 6 years in schedule delays. As a result of the cost and schedule increases under these four contracts, we calculate NASA will spend $13.1 billion through 2031 on boosters and engines.

We found long-standing management issues—including underestimating the scope and complexity of work, concurrent development and production activities, inadequate procurement workforce, and inappropriate use of award fees—caused the cost increases and schedule delays. Further, NASA's poor contract management practices are impacting the SLS Program and Artemis campaign, causing us to question $49.9 million in costs and award fees. Facing continuing cost and schedule increases, we found NASA is undertaking efforts to make the SLS more affordable. Under the RS-25 Restart and Production contract, NASA and Aerojet Rocketdyne are projecting manufacturing cost savings of 30 percent per engine starting with production of the seventh of 24 new engines. However, those savings do not capture overhead and other costs, which we currently estimate at $2.3 billion. For SLS boosters, NASA is procuring 10 boosters on a fixed-price-incentive-fee basis starting with Artemis IV—an important step in its affordability initiatives—but any additional requirements will limit these projected cost savings.

The OIG made eight recommendations to help increase transparency, accountability, and oversight of the SLS booster and engine contracts and NASA's affordability efforts.

NASA's Partnerships with International Space Agencies for the Artemis Campaign (IG-23-004, January 2023)

NASA's partnerships with international space agencies are critical to achieving a robust and sustainable presence on the Moon as a precursor to a human mission to Mars. Key early Artemis commitments from partner agencies include the provision of a Gateway habitat, communications satellites, spacecraft service modules, external robotics, astronauts, and lunar rovers.

We found, however, future international cooperation for Artemis may be hindered by a variety of factors. This includes the Agency's lack of an overarching strategy to coordinate Artemis contributions from international space agencies and entities. While the architecture, or blueprint, for the first three Artemis missions is well established, an overall architecture beyond Artemis IV for lunar exploration that includes estimated costs to be borne and responsibilities assumed by its international partners is not yet established. As a result, partners have insufficient information to work with their governments to develop their own budgets and identify potential contributions to the Artemis effort. In addition, U.S. export control regulations can be overly complex and restrictive which may limit NASA's international collaborations on Artemis. Finally, NASA's cost sharing strategies with its international partners for Artemis are still evolving and, in contrast to International Space Station operations where international partners contribute almost 25 percent of the costs, we estimate that less than 6 percent of the human space flight mission costs will be borne by international partners for the first three Artemis missions.

The OIG made ten recommendations to increase the effectiveness and affordability of Artemis integration efforts with international partners.

NASA's Management of the Mobile Launcher 2 Contract (IG-22-012, June 2022)

Key to NASA's goals of sustaining a human presence on the Moon and future exploration of Mars is the Agency's development of two mobile launchers that will serve as the ground structure to assemble, process, transport to the pad, and launch various iterations of the integrated SLS/Orion system into space. In 2019, NASA awarded a cost-plus contract to Bechtel National, Inc. to design, build, test, and commission a second mobile launcher to support larger variants of the SLS beginning with the Artemis IV mission. Valued at $383 million, the original contract had a performance period from July 2019 through March 2023.

We found that for completion of contract requirements and delivery of an operational ML-2, Bechtel estimated it would need an additional $577.1 million, for a total cost of $960.1 million, and an October 2025 delivery date rather than March 2023 as initially planned. Additionally, we found ML-2's substantial cost increases and schedule delays could be attributed primarily to Bechtel's poor performance on the contract, with more than 70 percent ($421.1 million) of the contract's cost increases and over 1.5 years of the delays experienced being related to the company's performance. These increases and delays were further compounded by NASA's management practices and decision to award the contract before the SLS's Exploration Upper Stage requirements were finalized. Further, NASA's usage of award fees did not improve Bechtel's performance.

The OIG made five recommendations to improve management of the ML-2 contract and contractor performance. In September 2023, the OIG initiated a new audit to examine the actions NASA is taking to control future cost growth and schedule delays.

NASA's Cost Estimating and Reporting Practices for Multi-Mission Programs (IG-22-011, April 2022)

NASA has a long history of groundbreaking accomplishments but has struggled to establish credible cost estimates for some major acquisitions; particularly, human space flight missions, which are comprised of multiple programs with numerous deliverables—like rockets and spacecraft—stretching over many years. As a result, Congress and other stakeholders lack meaningful visibility into the complete costs of NASA's major acquisitions. Without adequate transparency, it is difficult for stakeholders to hold the Agency accountable for these large, years-long expenditures of taxpayer funds.

We found that Congress is not receiving the federally mandated cost and schedule information it needs to make fully informed funding decisions for NASA's programs—specifically, the SLS, Orion, and Exploration Ground Systems—that support Artemis. NASA only made cost and schedule commitments to Congress to demonstrate the initial capability of each system. Even though NASA has multiple Artemis missions planned, it has not adjusted the three programs' life-cycle cost estimates or commitments to account for future missions. The result is incomplete cost estimates and commitments for these programs and missions.

In August 2021, the Agency made an update to NASA Procedural Requirements 7120.5F, *NASA Space Flight Program and Project Management Requirements*, which establishes the requirements, life-cycle processes, and procedures NASA uses to formulate and implement space flight programs and projects. NASA stated that it intended to establish new policies and procedures that would provide additional transparency for major programs with multiple deliverables and unspecified end points. Instead, it codified its poor cost estimating and reporting practices in a new policy that fails to comply with Title 51 of the United States Code, *National and Commercial Space Programs*, which requires the Agency to annually provide an estimate of the life-cycle cost for major programs, with a detailed breakout of the development cost, program reserves, and an estimate of the annual costs until development is completed. The policy also weakens NASA's ability to account for some risks in programs consisting of multiple projects, potentially affecting cost and schedule if risks are unidentified in the estimates.

The OIG made seven recommendations to ensure that all major programs and activities are reported to Congress in accordance with Title 51. In July 2023, NASA informed the OIG that it would not implement four of the recommendations.

NASA's Management of Its Astronaut Corps (IG-22-007, January 2022)

As NASA enters a new era of human space flight, effective management of its astronaut corps is critical to the Agency's success. With the upcoming crewed Artemis II mission, the margin of time available to identify skillset needs, recruit and hire additional astronaut candidates, develop a framework for Artemis training, and adjust current processes for sizing, aligning, training, and assigning its astronaut corps is quickly diminishing.

We found NASA's processes used to size, train, and assign the astronaut corps are primarily calibrated toward meeting the current needs of the International Space Station. However, work has begun to align NASA's astronaut corps to Artemis mission needs. As the Agency prepares for crewed Artemis missions, astronaut training needs will change. While the Astronaut Office is in the process of developing a framework for Artemis training, it has not been formally chartered. Delays in moving beyond the

current Space Station-focused approach increases the risk of delays in developing the necessary training to meet Artemis mission goals.

Additionally, as NASA moves to deep space Artemis missions, it has begun to review its policies and conduct additional studies on human health impacts from longer duration missions and missions beyond low Earth orbit. If the nature of Artemis missions medically disqualifies certain astronauts as a result of exceeding the Agency-set maximum level of radiation exposure because of the duration of the mission beyond low Earth orbit, NASA may need to adjust its astronaut corps size and assignment process.

The OIG made four recommendations to help ensure the astronaut corps is aligned to meet current and future mission needs.

NASA's Management of the Artemis Missions (IG-22-003, November 2021)

We found that NASA is projected to spend $93 billion on the Artemis campaign from fiscal years 2012 through 2025. However, as a result of NASA's decision not to classify Artemis as a formal program under the Agency's Space Flight Program and Project Management Requirements, Artemis officials were not required to develop an official Artemis-wide full life-cycle cost estimate. By failing to develop an official cost estimate that includes all relevant costs, NASA lacks transparency of the true funding requirements for a long-term Artemis effort.

Multiple factors contribute to the high cost of exploration system development programs, including the use of sole-source, cost-plus contracts; the inability to definitize key contract terms in a timely manner; and the fact that except for the Orion capsule, its subsystems, and supporting launch facilities, all components are expendable and "single use" unlike emerging commercial space flight systems.

For HLS, NASA has modified its traditional acquisition approach for large space flight programs to reduce costs, encourage innovation, and meet an aggressive schedule for its Artemis lunar landings. HLS will use less standardized milestone reviews and instead utilize other project management techniques throughout development and testing. While the HLS Program leveraged lessons learned and is modeled, in part, after the Commercial Crew Program, HLS tailored its programmatic milestone approach to better fit a services model approach versus the traditional hardware development program. Although these modified approaches have the potential benefit of decreasing costs and encouraging innovation, they also raise the possibility of technical changes later in development plus schedule and performance risks on NASA's human-rated systems.

The OIG made nine recommendations to increase transparency of costs and improve program management.

Conclusion

While Artemis I was a significant achievement for NASA, the Agency faces higher stakes as it flies astronauts on its Artemis II mission. We urge NASA leadership to continue balancing the achievement of its mission objectives and schedule with prioritizing the safety of its astronauts and to take the time needed to minimize any undue risk on this first crewed Artemis mission.

Moving forward, the Agency must continue to look for ways to reduce the enormous costs of the systems required to transport humans to the Moon and Mars safely within the funding allocated by Congress. Failure to reduce these costs will ultimately make the Artemis campaign unsustainable. At the same time, improved transparency of Artemis costs will be crucial to its success. Without NASA fully accounting for and accurately reporting the overall cost of current and future missions, it will be difficult for Congress, the Office of Management and Budget, and the American public to make informed decisions about NASA's long-term funding needs—a key to making Artemis a sustainable venture.

We look forward to helping NASA achieve its ambitious Artemis goals. To that end, we plan to continue examining key challenges in NASA's human exploration missions to the Moon and Mars.

Office of Inspector General

George A. Scott

George A. Scott assumed the role of NASA's Acting Inspector General in January 2024, following five years of service as the Deputy Inspector General. He most recently held the position of Interim Executive Director of the Pandemic Response Accountability Committee, overseeing over $5 trillion in coronavirus-related pandemic relief funds. Prior to joining NASA, Scott accumulated over 30 years of experience at the Government Accountability Office (GAO). During his time there, he served as the Managing Director of GAO's Homeland Security and Justice Team, where he oversaw GAO's efforts in the Department of Homeland Security (DHS) and the Department of Justice. This included initiatives to secure the nation's borders and infrastructure, as well as strengthen emergency preparedness and response capabilities. Scott has extensive oversight experience in DHS management, acquisition, financial management, and human capital issues. He also led oversight efforts on various justice programs and grants.

Scott, a graduate of the University of North Carolina at Chapel Hill, is a Certified Fraud Examiner. He is an accomplished speaker, having testified numerous times before Congress and presented at various conferences and training events.

Chairman LUCAS. Thank you. I now would like to recognize Dr. Griffin for five minutes to present his testimony.

TESTIMONY OF DR. MICHAEL D. GRIFFIN,

CO-PRESIDENT, LOGIQ, INC.

Dr. GRIFFIN. Mr. Chairman, Ranking Member Sorensen and Lofgren, Members of the Committee, thanks for the invitation to appear here today. I will try to use less than my five minutes, and I will be direct.

In my judgment, the Artemis program is excessively complex, unrealistically priced, compromises crew safety, poses very high mission risk of completion, and is highly unlikely to be completed in a timely manner even if successful. This matters because our self-declared adversary—adversaries—the Chinese Communist Party, together with their Russian partner, fully understand the role that being on the space frontier has in the world of global power politics. We seem no longer to understand that.

For the United States and its partners not to be on the Moon when others are on the Moon is unacceptable. We need a program that is consistent with that theme. Artemis is not that program. We need to restart it, not keep it on track, per the subject of this hearing. The Congress should provide specific direction to the executive branch to address this issue.

Thank you. I would request my full statement, written statement, be entered into the record and I'm—will stand down for your questions.

[The prepared statement of Dr. Griffin follows:]

Witness Statement for the Hearing

Returning to the Moon: Keeping Artemis on Track

U.S. House of Representatives
Committee on Science, Space and Technology
Space and Aeronautics Subcommittee

Rayburn House Office Building
Room 2318

Michael D. Griffin

17 January 2024

NASA, as well as the nation on behalf of which it executes our civil space program, should modify the strategy, tactics, acquisition approach and programmatic structure of human lunar return as it is presently planned. To the topic of this hearing, the Artemis Program should not be "kept on track"; it should be fixed and then prosecuted with all deliberate speed.

Strategic issues first. The agency has awarded fixed-price contracts to SpaceX and Blue Origin to carry out lunar landings for, respectively, $2.9 and $3.4 billion dollars (https://www.nytimes.com/2021/04/16/science/spacex-moon-nasa.html, https://www.reuters.com/technology/space/nasa-name-second-company-build-astronaut-lunar-lander-2023-05-19/). The cost of the Apollo Program over the 14-year period from 1960-73 is estimated to have been $257 B in 2020 U.S. dollars (C. Dreier, *An Improved Cost Analysis of the Apollo Program*, Space Policy, https://doi.org/10.1016/j.spacepol.2022.101476). It is reasonable to believe that with the flight experience and space industrial infrastructure that exist today, human lunar missions could and should be executed for considerably less than Apollo. It is grossly unrealistic to suggest that they could be done for 1.5% of Apollo's cost. The award of these unrealistically low fixed-price contracts makes it clear that cost reasonableness was not a factor in ranking these contract awards. The further implication is that the United States is not yet serious about a program that should be regarded as a core national interest – returning U.S. and international partner astronauts to the Moon before our self-declared adversaries can do so.

As in the 1960s, we are again faced with near-term peer competition in space, this time with the Chinese Communist Party and, once again, potentially Russia: (https://www.newsweek.com/russia-approves-plan-establish-lunar-base-china-1848731). For the U.S. not to be able to put its own and partner astronauts on the Moon, to be watching on the internet while adversary powers do so, makes a statement about a shift of global power and preeminence that we ought not to allow. People and nations align themselves with leaders; for most of the last 80 years that has been the United States, in partnership with our European and

Western Pacific allies. Are we prepared to relinquish that leadership to China? If not, and if we view preeminence in space as part of that leadership and therefore an element of national security, then it is again necessary to prioritize urgency of execution.

Underlying the above is a key theme: we cannot separate civil space exploration from national security space. It's one national program, artificially separated at birth by President Eisenhower to demonstrate to the world, and especially to the Soviet Union, that we were a peaceful nation, exploring and developing space for peaceful purposes. But the reality is that the creation of NASA was a national security initiative from the start, a response to the Soviet Union's launch of Sputnik.

National security takes many forms beyond raw power projection. In exploring and developing the space domain we are pioneering the human frontier. Even a casual reading of history shows that every great nation was on the frontiers of its time; this is almost a defining characteristic of great powers. To quote from President Kennedy's "man, Moon, decade" speech, where mankind goes, free men must fully share. The point is that value systems matter. The United States mounted one of the most powerful yet non-aggressive responses in history to the Soviet Union's launch of Sputnik. Had the first satellite been launched by the United Kingdom, the United States might have been a bit chagrined that we weren't first, but the response would simply not have been the same. The values of the United Kingdom and our own are highly aligned; the values of the United States and the Soviet Union were about as antithetical as it was possible to be. This difference was critical to our response to Sputnik, as it should have been.

The reality is that decisions are made, standards are set and values are established on a frontier by the people who show up, not by those who stay home and watch. The society that sets those standards (as we have done for global air transportation since the end of World War II) and establishes the key infrastructure emerges as first among equals, the proper goal for the United States.

Finally, when a society can do things that others cannot it commands a degree of respect that is by itself a valuable national security asset, possibly more so than in many instances of the exercise of "hard power". Quite simply, the very best people want to come to the place where the very best things are being done. It is quite instructive to observe how many key figures in the Manhattan and Apollo programs were immigrants, a number that was hugely out of proportion to the rest of the population. To quote an observation by former Deputy Under Secretary of Defense for Research and Engineering Dr. Lisa Porter, the United States is a country where a six-sigma individual can flourish. They are the people who create, in the words of another quote attributed to JFK, the rising tide that lifts all boats. Space exploration attracts such people. That is something in which we should take pride and is an asset to be nourished.

These are the forms of national security that NASA enables, and that we should take to heart in crafting our national space exploration strategy.

Tactically, the selected mission architectures pose significant concerns. SpaceX's approach requires an impractically large number of orbital refueling operations for even a single lunar mission (Space News, 17 Nov 2023; https://spacenews.com/starship-lunar-lander-missions-to-require-nearly-20-launches-nasa-says/), while Blue Origin's mission design depends on the development of one of the most difficult enabling technologies for long-duration space flight, zero-boiloff cryogenic fuel storage (https://en.m.wikipedia.org/wiki/Blue_Moon_(spacecraft)). These architectures feature concepts – cryogenic propellant storage, likely in large depots with low, controllable boiloff – that are critical to long-term, sustainable human space exploration. But while important, their development is unlikely to be completed easily or quickly, and over the last half-century we have used up the time that could have been devoted to the evolution of Apollo-era systems to a more sustainable architecture. Like it or not, we are engaged in a competition with others who do not wish us well; timeliness matters.

There are other concerns as well.

Crew Safety

The present Artemis mission architecture requires staging operations at a Gateway based in a lunar polar near-rectilinear halo orbit (NRHO) with a 6.5-day period and dimensions of 3,000 km x 70,000 km altitude above the lunar surface. This approach is said to offer two significant advantages: the Orion spacecraft, which as discussed below has limited ΔV capability, can get into and back out of this orbit on the way to and from the Moon, and any point on the lunar surface can be accessed from the staging area. The first of these issues can be addressed by far simpler means, discussed below, and the second is not unique to NRHO – it is a characteristic of any polar orbit.

However, these points are trivial in comparison to the major disadvantage of staging from NRHO, which is that immediate return to the Gateway from the lunar surface is possible only on 6.5-day centers. If a lunar crew encounters a problem on the surface that mandates a return to the comparative safety of the Gateway, then depending upon when that problem occurs, a multi-day wait may be required. It is possible in some scenarios to wait in low lunar orbit (LLO), but access to the Gateway is only possible at periodic intervals.

With present technology, flying in space is just barely possible; even in Earth orbit it is both difficult and dangerous. Expeditions to the Moon will be even more demanding. From a safety perspective, no early human lunar mission should knowingly accept the risk of stranding a crew, whether on the surface or in lunar orbit, for days at a time. No mission architecture should be contemplated without, as in Apollo, the capability to leave the surface and rendezvous with a safer habitat within a few hours. Somewhat like the first experience of "wintering over" in Antarctica, when enough lunar surface infrastructure has been emplaced to allow a viable long-term shelter-in-place option to be implemented, the crew abort strategy can be reconsidered. Such is not the case for early human lunar return. The Artemis program has not been designed with this consideration in mind.

Reliability and Mission Risk

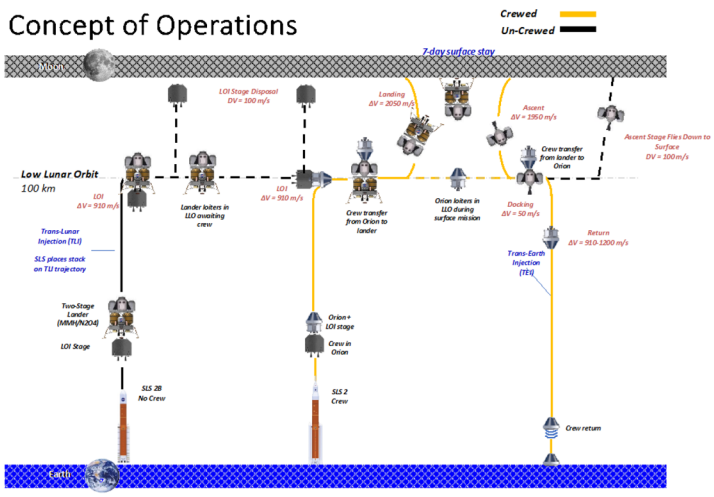
Leaving safety aside, mission architectures requiring multiple complex operations in series, such as propellant supply launches and cryogenic fuel transfer, are inherently less reliable than those requiring fewer. The table below makes this point; the left side of the table specifies a postulated reliability for each launch and propellant transfer operation, while across the top is shown a varying number of such operations.

Reliability of One Operation	Number of Operations			
	5	**10**	**15**	**20**
99%	0.95	0.90	0.86	0.82
98%	0.90	0.82	0.74	0.67
97%	0.86	0.74	0.63	0.54
96%	0.82	0.67	0.54	0.44
95%	0.77	0.60	0.46	0.36

The results speak for themselves. Even if (for example) it is assumed that each single operation, e.g., launch plus propellant transfer, can be performed successfully 98% of the time, i.e., with a 1-in-50 failure rate, a mission requiring ten such operations in a specified campaign window will fail to be completed within that window 18% of the time. As a practical matter, mission architectures requiring multiple launch and propellant transfer operations will be very difficult to complete with a reasonable likelihood of overall success. Congress should question whether this is a gamble that, from either the fiscal or national prestige perspective, it wishes to support.

A Lower-Risk Approach: A Two-Launch Solution for Human Lunar Landing

Early lunar return missions that meet NASA's basic requirements – four people on the surface for a week at any location – can be achieved using technology and systems that are largely available today. One straightforward approach is discussed below. It requires two SLS Block 2 heavy lift launches, each carrying a Centaur III upper stage; an Orion command and service module; and a two-stage storable-propellant lunar lander, yet to be designed. A schematic view of this approach is shown below:



Mission Sequence

1) A payload stack consisting of a partially fueled Centaur III upper stage and the fully fueled but uncrewed Lander is launched as cargo on the SLS Block 2B cargo variant with the capability to put about 45 metric tons (mT) into a trans-lunar insertion (TLI) trajectory.

2) The Centaur III is fueled with sufficient propellant (including allowance for boiloff) to provide a ΔV of about 1 km/s for the payload stack and is used as a lunar orbit insertion (LOI) stage to deliver the Lander to LLO to await the crew.

3) At a later time, the crew is launched on an SLS Block 2 crew variant (41 mT to TLI) to LLO in Orion using the same Centaur III LOI stage as for the Lander. As the fully fueled Orion has a mass of 27 mT, there are potentially several tons of margin for this launch.

4) The Orion crew rendezvous with the Lander in LLO and transfers crew and possibly additional equipment and provisions enabled by the mass margin for the Orion launch.

5) The lander descends and lands out of LLO. The crew executes its surface mission, launches back to LLO in the ascent stage, rendezvous with Orion, transfers crew, and deploys the ascent stage into a controlled lunar surface disposal.

6) The crew returns to Earth from LLO in Orion. The Orion ΔV capability of 1.25 km/s is more than sufficient for the trans-Earth insertion (TEI) maneuver.

LOI Stage

This stage is needed because the presently existing Orion service module ΔV capability of 1.25 km/s is sufficient for either insertion into or return to Earth from LLO, but not both. If developed for this purpose, it is likely to be advantageous to use the LOI stage also for insertion of the Lander into LLO. However, depending upon the efficiency of the Lander descent propulsion engine, it can be reasonable to consider making the Lander descent stage large enough to accommodate the additional, less-efficient, storable propellant necessary for insertion into LLO.

The present analysis does not incorporate this assumption. It is conservatively assumed here that the LOI stage will be used for both tasks and hence is sized for the more difficult requirement, Lander insertion into LLO. To this point, the fully fueled Centaur III with a single RL10C-1 engine (presently used as an upper stage for Atlas V) has the following parameters:

Specific Impulse (Isp)	–	450 s
Dry Mass	–	2.25 mT
Propellant Mass	–	20.83 mT
Gross Mass	–	23.08 mT
Diameter	–	3.05 m
Length	–	12.7 m

The required insertion ΔV from a three-day trans-lunar coast trajectory to LLO is approximately 1 km/s, depending in detail on a variety of factors including the choice of landing site. Assuming a required ΔV of 1 km/s for this analysis, the mass of propellant required for the Centaur III to insert the initial payload stack (M_i = 45 mT) into LLO is

$$M_p = M_i (1 - e^{-\Delta V/gIsp}) = 9.2 \text{ mT}$$

and consists of about 8 mT of liquid oxygen and 1 mT of liquid hydrogen.

Propellant boiloff, primarily of the liquid hydrogen fuel, must be included in the cargo launch. For the production Centaur III, flown-vehicle data shows the loss rate to be 13-17% per day; with a few layers of insulation this can be reduced to 5% or less. (https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwj2hPPF5t-DAxWdF1kFHbJOBywQFnoECBMQAQ&url=https%3A%2F%2Fwww.ulalaunch.com%2Fdocs%2Fdefault-source%2Fextended-duration%2Fcentaur-extensibility-for-long-duration-2006-7270.pdf&usg=AOvVaw1Vzv5kb-HhwZlszEs8dIlI&opi=89978449). With this, the Centaur will lose less than 200 kg of propellant during a three-day trans-lunar coast. Including an allocation for a docking mechanism and other airborne support equipment for the Lander/Centaur cargo stack yields an allowable Lander mass of 32 mT, as shown:

SLS Block 2B TLI Payload	–	45 mT
Less		
Dry Mass, Centaur III	– 2.3 mT	
LLO Insertion Propellant Mass	– 9.2 mT	
Fuel Boiloff Allowance (5%/day)	– 0.2 mT	
Airborne Support Equipment Allocation	– 1.3 mT	
Subtotal for LOI Requirements	–	13 mT
Maximum Allowable Lander Mass	–	32 mT

The mass of the required LOI stage itself, slightly less than 12 mT, is about half the size of the Centaur III. For a lunar return mission, the stage could be flown as-is with a reduced propellant load, or a modified version with shorter tanks developed if desired. Also, the RL10C-1-1 engine variant for the Centaur V, the upper stage of Vulcan Centaur, offers an improved specific impulse of over 453 seconds. Given the time available before a lunar return mission will be executed, it may be feasible to incorporate this engine into a modified Centaur III LOI stage, thus gaining about 130 kg performance improvement.

Lunar Lander

To establish a baseline, the J-Series Apollo lunar landers (Apollo 15-17) had masses of less than 16.5 mT, including the 210 kg lunar rovers carried on each of these missions, and sustained two crewmembers for three days. Scaling of this experience would suggest that a four-person, 32 mT vehicle capable of supporting a 7-day mission is well within conservative design limits.

Improvements are possible, for example the incorporation of storable, low toxicity "green propellants" rather than the legacy, highly toxic, difficult to handle nitrogen tetroxide/hydrazine storable propellant combination. However, in the interest of offering a low schedule risk approach, the present analysis does not presume such advances.

Acquisition Strategy

The fundamental flaw in the Artemis acquisition approach is the assumption that the U.S. government can and should leverage so-called "commercial space" for national purposes, and that this paradigm is applicable to human spaceflight. It is debatable whether, in general, "commercial space" is other than a catchphrase intended to differentiate traditional prime contractors from newer firms aspiring to obtain government contracts without the excessive and stifling regulatory framework surrounding traditional government acquisition. However, it should be clear that no significant fiscal return on investment in human lunar missions can be expected in the foreseeable future without significant government subsidy.

It is thus NASA's responsibility to acknowledge that it is the only significant customer for human missions to the Moon and that it must therefore establish and direct a credible mission design to which contractors can bid, and to develop an equally credible cost estimate to implement that design, rather than agreeing to unrealistic firm fixed price (FFP) bids for complex development programs. Government FFP contracts that are underbid leave both sides stuck in

a bad deal with only a few possible but unsatisfactory outcomes: the contractor demands additional money to finish the program and the government pays it, the program is ultimately canceled because the government doesn't want to pay, or performance is reduced in a compromise between the amount of money the contractor wants and that which the government is willing to pay. There is a long and depressing history of such efforts: (https://www.defensenews.com/industry/2024/01/09/cautionary-tale-how-boeing-won-a-us-air-force-program-and-lost-7b/). We should not add human lunar return to the list.

If our nation is serious about returning to the Moon, this time to stay, then it properly requires an investment by the Congress on behalf of the public it serves. Congress and the public should expect that investment to be expertly managed by Executive Branch officials who are responsible and accountable for the quality of their decisions and the direction they provide to industry to implement those decisions. NASA's acquisition approach should reflect that fundamental principle.

Programmatic Considerations

The Artemis lunar landing missions as presently planned significantly compromise crew safety, carry high mission execution risk, are highly unlikely to remain on schedule, and are being executed via an inappropriate acquisition approach with grossly unrealistic fixed-price cost assumptions. These facts require hard decisions to be made if success is to be attained in the end. Congress must use its power of the purse to direct the Executive Branch to implement these decisions.

Or, we can just kick the can down the road, as we have been doing for more than five decades now.

Specifically, the existing contracts should be terminated for the convenience of the government and a new program initiated along the lines described above. Those who object will observe that termination for convenience will not allow significant funding to be recaptured from the existing fixed-price contracts, and this is correct. But to continue programs that we know will not achieve our goals distracts us from what must be done and damages NASA's and the nation's reputation, even if they are being executed for free. We need to focus our efforts on an approach that we know will work in a timely manner with the lowest mission risk and the greatest crew safety we can provide. To this point, while the analysis presented here offers a point design to illustrate concept feasibility, a sensitivity study should be conducted to establish the parametric feasibility space within which the two-launch mission design can be optimized.

Sustainability of our future space architecture does matter. Efforts to develop systems that expend fuel rather than hardware are important to that future. Because it is at the far end of the lunar ΔV gear train, a single-stage reusable crew lander is the most important of these developments. Thus, the development of cryogenic propellant transfer and zero-boiloff storage technologies should be pursued. But the development of these technologies will not be quick or easy, and timeliness is presently the more important feature for our nation's human lunar return program. Similarly, while NRHO and the Gateway as presently conceived are irrelevant to

human lunar return, a transportation node or nodes like the Gateway will be valuable components of a sustainable future lunar architecture if placed in a more useful staging orbit than planned today.

But regardless of these finer points, the straightforward approach outlined here could put U.S.-led expeditions on the Moon beginning in 2029, given bold action by Congress and expeditious decision making and firm contractor direction by NASA. This is not the path being pursued at present and the existing Artemis contractual and programmatic structure will not support it. A new program, architected and managed by people who are clearly qualified for the job, should be initiated and executed with funding adequate to carry out this urgent and important national mission.

Michael Griffin
Co-President

Michael D. Griffin is the Co-Founder and Co-President of LogiQ, Inc., a company providing high-end management, scientific, and technical consulting services. He was previously the Under Secretary of Defense for Research and Engineering, and in that role shared responsibility with the Deputy Under Secretary for research, development, and prototyping activities within the Department of Defense. In prior roles he was the Chairman and CEO of Schafer Corporation, the King-MacDonald Professor at University of Alabama in Huntsville, the Administrator of NASA, Space Department Head at the John Hopkins University Applied Physics Laboratory, President of In-Q-Tel, CEO of Magellan Systems, and EVP and General Manager of Orbital ATK's Space Systems Group. He is a member of the National Academy of Engineering and the International Academy of Astronautics, an Honorary Fellow of the American Institute of Aeronautics and Astronautics, a Fellow of the American Astronautical Society, and a Fellow of the Institute of Electrical and Electronic Engineers. He has received the NASA Exceptional Achievement Medal, the AIAA Space Systems Medal and Goddard Astronautics Award, the National Space Club's Goddard Trophy, the Rotary National Award for Space Achievement, the Missile Defense Agency's Ronald Reagan Award, and has twice been awarded the Department of Defense Distinguished Public Service Medal. He holds seven earned degrees and has been recognized with honorary doctoral degrees from Florida Southern College and the University of Notre Dame. He is a Certified Flight Instructor with instrument and multiengine ratings, a Registered Professional Engineer in Maryland and California, and the lead author of two dozen technical papers and the textbook *Space Vehicle Design*.

Chairman LUCAS. Without objection, so ordered.

I turn to myself now for five minutes for questions.

Ms. Koerner, NASA announced last week that Artemis II is now targeted for launch in September 2025 and Artemis III targeted for launch in September 2026. Can you share the scheduling margin built into the updated Artemis II and III launches?

Ms. KOERNER. So thank you, Chairman Lucas, appreciate the question today. We are—have adjusted the Artemis II schedule based on crew safety. As you recall, from coming out of Artemis I we had a tremendously successful mission, and one of the follow-on investigations from that mission is the performance of the heat shield. That has taken us some time to analyze the data. The heat shield performed perfectly from a thermal perspective, but we saw some unusual characteristics, and we want to fully understand that before we put Reid, Victor, Christina, and Jeremy on Artemis II. So that has contributed to the delay in the mission. We have sufficient time to complete that investigation with a 10-month adjustment to that launch schedule.

Also, with Artemis II, we have additional capabilities on the Orion spacecraft. The life support systems have proven to be more difficult and challenging to develop. And during the testing of some of those systems, we identified an issue with a digital motor controller that has impacted our ability to be able to continue the processing the vehicle as previously planned. The additional time that we have given ourselves in the adjusted schedule permits us the opportunity to address the challenges that we've seen with that digital motor controller.

So we have a number of issues, and those issues are all encapsulated with this margin that we have on the schedule for this September 2025. There is margin built into that schedule for us to complete all of the necessary testing and to address all of the regular processing that we—lessons learned that we had from the Artemis I launch.

Chairman LUCAS. To the rest of the panel, based on these margins, do you believe that these revised schedule launches—dates are realistic? Whoever would care to touch that first.

Mr. RUSSELL. Yes, Chairman Lucas, I can jump in. I think for Artemis II, certainly, that that provides more time to get through the issues and figure out the heatshield life support challenges that Ms. Koerner referenced. The one thing that jumps out with the revised Artemis III date is the span of time between Artemis II and III is one year. So if you consider the successful conclusion of Artemis I in 2022 and now it's going to be a few years to the '25 date to do essentially the same Artemis test flight the second time with the crew, Artemis III is more complicated, so there's not a lot of time, and as you saw with Artemis I, there are things that are going to happen that you need to learn that you need to investigate. One year is not a lot of time to do that learning, turn around and be ready for a September 2026 launch date. So that's the one scheduled pressure that we see with the new dates.

Chairman LUCAS. Any observations, gentlemen, that you care to add?

Dr. GRIFFIN. I would say that the Artemis circumlunar mission is, I think, very doable on the timescale that NASA has said. I

don't think the Artemis III, the landing mission, is at all realistically scheduled.

Mr. SCOTT. Thank you, Chairman Lucas. I think NASA will continue to be challenged on the schedule front, particularly with the Artemis III mission. Now, historically, certain spaceflight missions, in terms of going from contract to development have taken, you know, 8 1/2 years. And with HLS, NASA was trying to do it in a much more condensed timeframe. So I think based on lessons learned from Artemis II, I think that the agency will be better positioned to come up with a more realistic launch date for Artemis III.

Chairman LUCAS. Ms. Koerner, can you share with the Committee what milestones NASA uses to measure contractor performance on the Human Landing System and spacesuit contracts and, along with that, what the consequences are for contractors if they don't meet the milestones by the assigned deadline?

Ms. KOERNER. So with regards to the contract milestones, we have a number of milestones that are significant for the Artemis III landing—ultimate crew landing. The first would be an uncrewed demo that has to happen prior to a crewed landing. We are keeping track on SpaceX, our prime contractor, for the Human Landing System. We're keeping track of their progress. If you recall, they've had a number of test flights, and they will actually conduct their next test flight here, likely in the February timeframe. And they have good scheduled margin to support that launch.

We are anticipating a number of launches in calendar year '24 by our SpaceX industry partners to support the development of not only the Human Landing System capability but also their cryogenic fuel transfer capability, which is essential for us to be able to understand the process for refueling the Human Landing System prior to when we send our crews.

So we have various milestones throughout their contract that enable us to be able to measure their performance. We also have recently made contract modifications that allow us to incentivize them to meet those milestones on the schedule that we need in order for us to support the launch date of the crew in September 2026.

I will note that we do parallel processing of a lot of our missions, so it's not like we have just one year between Artemis II and Artemis III to get everything accomplished. We are right now working on the hardware for Artemis III, and in particular, I will note things like the European Service Module will be shipping here in the spring to the Kennedy Space Center for processing and to complete assembly of the Orion spacecraft. So I fully expect that before we ever launch Artemis II, Artemis III vehicle processing will be far enough along that we'll be able to take advantage of the one year between the two missions to be able to fully be ready for the Artemis III mission in September of '26.

I will also note that if you recall the press conference that we did just last week when we announced the slip to those launch dates, we had our 11 industry partners online with us for that, and all of them has signed up for the launch date of Artemis III that we are currently showing.

Chairman LUCAS. Thank you. And before I yield to the Ranking Member, I would note that I've had several conversations with the Administrator, and he has a great deal of confidence in you. I just want to pass that along.

Ms. KOERNER. Thank you.

Chairman LUCAS. And with that, I yield back and turn to the Ranking Member, Mr. Sorensen, for five minutes.

Mr. SORENSEN. Thank you, Mr. Chairman.

Ms. Koerner, we have heard from GAO and the NASA IG about the importance of cost transparency for Artemis. Artemis is not just one system, one mission, or even one capability. It's a set of increasingly complex missions and activities. NASA now has successfully completed Artemis I. Could you explain how NASA is documenting the lessons that we have learned in Artemis I such that we are applying those lessons to Artemis II and III?

Ms. KOERNER. Certainly. So we did a very extensive lessons-learned process coming out of Artemis I that enabled us to at every level within the organization and within the hardware production, whether it's at the contractor level or NASA doing integration and analysis, to be able to factor that into the Artemis II learning, as well as future missions.

As I indicated previously, we have—we're—we have a lot of missions in flow and in development simultaneously. What that does is it enables us to—when we learn a lesson on Artemis I, we can flow that into all of the development that we have currently ongoing. It also allows us if, for example, we've already built some equipment for Artemis II, we already have Artemis III at nearly the right level in its production to be able to make modifications to that hardware and then bring it forward to incorporate it into Artemis II, just as an example. So having the rich, I'll say, production cadence that we have established with our Artemis missions and our hardware has enabled us to be able to incorporate all of those lessons learned.

I will also note to the comment about the cost and cost transparency, one of the challenges that we face in answering a per-mission cost is our contracts are set up to do bulk buys. In other words, we get—if I go buy three of something, I can get it less expensive than if I buy one of something three times. So when we have—establish our contracts and we purchase some of our equipment, those bulk buys give us cost savings. But what those do is it lumps costs together in by program and by purchases. It doesn't allow us—we don't, for example, get appropriations for Artemis missions. I don't get an Artemis I appropriation and an Artemis II appropriation. I get one for SpaceX—excuse me, for HLS, for Orion, for the Space Launch System.

So aggregating those costs where we'd make bulk buys and we make purchases based on different contract mechanisms makes it very challenging for us to put together a per-mission cost. But we are very transparent in the cost numbers that we have with the contract structures that we have in place and with the way that we are appropriated.

Mr. SORENSEN. So you would say that it is an investment—Artemis I is an investment in II, and then II is an investment——

Ms. KOERNER. All of these missions build on each other, yes, sir.

Mr. SORENSEN. Great. You know, humans landed on the lunar surface in 1969. In the year 2024, we still use some of the same technology that was developed, you know, some 55 years ago. And I like to say that we wouldn't have computers in our pockets if we didn't have that investment. So, Ms. Koerner, could you speak to what returning to the Moon and eventually going to Mars will mean for the science and technology of tomorrow?

Ms. KOERNER. Yeah, if you'll permit me an analogy, so I was here, by the way, and watched Apollo 11 astronauts walk on the Moon, so I remember that. And I remember the inspiration that that was to me and to those from my generation. The analogy that I'll use for you is, right, a car today and a car from the early 1900's look pretty similar in some regards. They have a steering wheel, they have wheels, they transport people, any number of people depending on the design. But when you look inside the engine, they're very different. They're very different machines.

The technology that we're going to the Moon with this time is very different. And the technologies that we're developing are actually developing entire industries to support those technologies, industries, craft trades, that things of that nature that are helping the economic engine of the United States, as well as our partnering countries.

Mr. SORENSEN. I lived in east Texas, and I remember everything about that Saturday morning when Space Shuttle Columbia disintegrated. I still feel it to this day. Next week, we will recognize NASA's Day of Remembrance to honor the heroes that made that ultimate sacrifice to advance our Nation's spaceflight and exploration programs.

I know my time is waning. How do we plan to communicate the upcoming risk as we continue to go farther? Would anyone like to answer that?

Ms. KOERNER. I would like to at least start out by doing that. So many of us lived through the tragedy of Columbia, and many of us witnessed the tragedy of Challenger as well. And those of us who are still within the agency take those lessons very seriously, and we make sure that when we have a day of remembrance, we remember not only the tremendous lives that these people lived and the sacrifices that they made, but we remember why we do what we do and why we are so focused on risk and on safety, which is the reason—for example, we did not hesitate to adjust the launch date for Artemis II when it became evident that safety was of utmost importance with the challenges we were facing.

Mr. SORENSEN. Thank you.

Chairman LUCAS. The gentleman's time has expired.

The Chair now recognizes the gentleman from Florida, Mr. Posey, for five minutes.

Mr. POSEY. Thank you very much, Mr. Chairman.

The Chinese Communist Party threatens almost every component of our government and the lives of Americans obviously. And, Ms. Koerner, your written testimony, you didn't mention China at all. Mr. Russell, you mentioned diversity, but you didn't mention China. Mr. Scott didn't mentioned China. Dr. Griffin, your testimony does mention our adversary China, and I wonder if you ex-

pound upon why you went into such detail, for the clarification of others?

Dr. GRIFFIN. In my judgment, China—and I don't want to say China. I want to say the Chinese Communist Party, fully understands and frequently says that their goal is to be the world's great power. They regard the Western democracies as decadent and outmoded and ineffective and inefficient. China's President—he has other titles—Xi bullies neighboring countries, presumes to take control of international waterways, supervises a military establishment that has recently sunk other people's ships fishing in their own waters. Everything about the behavior of the Chinese Communist Party suggests that they are their adversary, and they say so.

To allow a situation to develop where the human frontier is populated by our adversary and we are not there should be unacceptable to this Nation and to our Western and Asian partners. It should be unacceptable. We are not on a path to recognize that. The rest of the world looks and will always look to the nations that occupy the frontier and exploit the frontier and extend the frontier as leaders of the world. I believe that's the position that the United States should occupy in preference to our adversaries. Thank you.

Mr. POSEY. Thank you, Dr. Griffin. And you mentioned frontier. Add to that ultimate military high ground. Whoever controls space will control the destiny of this Earth.

Dr. GRIFFIN. As you know, I've spent considerable time in the national security side of our space programs as well, and I really consider them to be one program. But I came here today to discuss civil space, sir, and——

Mr. POSEY. Yes.

Dr. GRIFFIN [continuing]. We can discuss military space at another occasion.

Mr. POSEY. How should America make it our goal to ensure that we emerge as first among equals when it comes to setting standards? We've had a couple of hearings on that.

Dr. GRIFFIN. Well, the standards are set by the people who show up. They're not set by the people who watch what happens with others. So by returning to the Moon in a focused and expeditious manner, which we are not today, we will inevitably bring along—we will be required to bring along communications and navigation and other infrastructure systems, which we expect others will use as well.

By that mechanism, we will have established the standards, just as we did with the ICAO (International Civil Aviation Organization) starting at the end of World War II for global air transport. But again, those are facts on the ground that are created by the people who are on the frontier first. They are not created by the people who follow.

Mr. POSEY. Now Thank you, Doctor.

Now, Ms. Koerner, what specific steps are being taken to address what some consider to be the outdated gas and propellant pipelines and other ground systems at Kennedy Space Center to ensure that we have the capacity to support our booming commercial space sector?

Ms. KOERNER. So the infrastructure at the Kennedy Space Center, as well as at all of our centers, is very much aging, and we are aware of that within the agency. I will tell you from an Artemis perspective, we are investing heavily in the capabilities that we need to support the Artemis mission. Last year, we had over 70 launches from the Florida Space Coast. It's an exciting time for all of us in the space industry. Most of those were on the cape side, but we also had a number of them from our side on the—at the Kennedy Space Center.

And in order—excuse me. In order to support those, we have poured heavily, as I said, into the infrastructure. But we also recognize that there's still more that is needed there. Many of the launches from that area are commercial in nature, and we have use agreements with our commercial and industry partners that allow them to actually invest in the infrastructure as well. We know as an agency that our infrastructure is older than I am in some cases. And our NASA leadership has established what's called NASA 2040, which is an internal effort to look at all of the agency's infrastructure and mission support functions to be able to set us up properly for what the agency's mission is going to be in the 2040 timeframe. Infrastructure like that at the Kennedy Space Center, which is critically important to us in Artemis, is part of that discussion.

Mr. POSEY. Thank you, Mr. Chairman, and I yield back with a request that we also have a weather modification technology hearing again. Thank you.

Chairman LUCAS. Duly noted. The gentleman yields back.

The Chair now recognizes the Ranking Member of the Full Committee for five minutes.

Ms. LOFGREN. Thank you, Mr. Chairman.

Now, as I understand it, our effort to go to the Moon is going to rely on at least five major, distinct, multibillion dollar development programs that have to sync up perfectly. The SLS rocket, the Orion crew vehicle, the Exploration Ground System, the Human Landing System, as well as the spacesuit. I am—they're all going to be procured under different acquisition mechanisms. I particularly would like to know about the cryogenic fluid management and other new technologies. What happens if these five major programs don't sync up or if one gets slowed down? How do we proceed? Can you address that, Ms. Koerner?

Ms. KOERNER. Certainly. Thank you for the question. So we established the Moon to Mars program office just last year, pursuant to the *NASA Authorization Act,* to do just what you're talking about, to integrate all of those programs that are essential for Artemis and ensure that we are properly level-loading the risk between those programs so that they all converge together for a mission. We know that it's going to be challenging and difficult for us to—especially as we get into later missions to get all of those missions to align to the same timeframe. And so we have put our contracts in place to continue to develop hardware for the subsequent missions so that we can be ready to execute a mission as soon as all the elements are available.

We also recognize that there might be some development and technology challenges that come along the way, and so we are—

have a very flexible and adaptable mission structure that allows us to be able to make updates to our mission profiles if we need to in the event that one element in the Artemis program's cadre does not make it in time for the original planned mission.

Ms. LOFGREN. Well, just following up, if one of these elements is delayed, what happens to the whole program?

Ms. KOERNER. So we would—depending on how long the delay is, depending on the reason for the delay, we would potentially execute a slightly modified version of that mission. And I mention that only because we have set in place for our agency a process that allows us to keep our eye on the exploration objectives, and all of our missions contribute to those exploration objectives. So we can modify the mission content to adjust to still accomplish those objectives. Unlike, for example, when we flew space shuttle missions, each mission was very independent and different. With Artemis, we're building a capability, not just a launch capability, but a capability in cislunar orbit, capability on the surface of the Moon over time. And as any large-scale development activity knows, when you do that you can make adjustments for when something gets delivered late or something shows up differently, you focus then on another aspect or another objective that you're trying to achieve.

Ms. LOFGREN. Let me ask this. The IG issued a report in October of last year about the supply chain monitoring. What has NASA done to adopt those recommendations relative to the Artemis supply chain?

Ms. KOERNER. So we certainly do appreciate our governing organizations that provide us feedback and contribute to the benefit of the program. We have looked at our supply chain and supply chain management and looked at how we can better manage that, and I'll speak again to what I mentioned previously. The Moon to Mars program office, that office was deliberately established so that we can connect all of the what were previously disparate programs and look across the board and address some of these supply chain issues.

Ms. LOFGREN. I want to say I also saw the landing on the Moon. It was a stunning thing. But I'll confess at the time, I thought, how is this helping us here on Earth? Now, I listened closely to Dr. Griffin's assessment of the Chinese. I completely agree with him. I do think it's important to outline for the American public why this matters to them. And I'm wondering, Ms. Koerner, if you could outline efforts that NASA is making to explain why this matters to America. And, by the way, I concur in the Chairman's comment that the Administrator has huge confidence in you, so if you could answer that.

Ms. KOERNER. Thank you. That's a little bit embarrassing, I'll admit. But I'll say one of the efforts that we have done within our agency within the last couple of years really focus on the why, the why of exploration. And we identified three pillars associated with that why: science, national posture, and inspiration. Science, I think, is obvious. It's the engine that generates economic benefit wherever it goes, in addition to inspiring the next generation of STEM, as well as teachers and those of us who look to the scientific discovery with wonder and decide that is something I want to learn more about and want to pursue.

Additionally, national posture, I think we've spoken to that a little bit already with Dr. Griffin's testimony. But I'll state we believe that—and our Administrator spoke about it just last week—that we will be on the surface of the Moon before China is. And it's our intent for that to happen. Now there are other government agencies that can provide a much more detailed briefing that we can do in a different environment than here that could give you more insight and information about China's progress and about our progress along those lines.

Let's see. I mentioned the—two of the three pillars. The third one, inspiration, again, you know, it's what inspired me to pursue a STEM career. It's what inspired many people in my generation and really developed that next generation that we're starting to see. And we hope to do that inspiration not just here in the United States, but around the world.

Ms. LOFGREN. Well, I thank you very much. Just by the way before I yield back, we had an astronaut come and meet with students in Hollister, California, just a few days ago, inspiring those young people. It's very important.

I thank you, Mr. Chairman, and yield back.

Chairman LUCAS. The gentlelady yields back.

And before I turn to my next colleague for questions, I would note since it's true confession time, yes, I was nine years old that summer, too. But in my part of rural Oklahoma, we had one television station. We only had AM radio and this strange concept called party lines for a phone system.

Ms. KOERNER. I remember those.

Chairman LUCAS. You know exactly how many relatives you have based on what you've said on the phone.

That said, I turn to the gentleman Mr. McCormick for five minutes.

Mr. MCCORMICK. Thank you, Mr. Chair.

The Artemis mission is not only about returning humans to the Moon, but about advancing technology, fostering international cooperation, stimulating the economy, inspiring the public, and securing the United States' position as leaders in space exploration.

Similarly, in the 1960's, we were again faced with the space race only this time with the Chinese, not just the Russians. The United States must be a leader in space, and we must lead by setting the standards we know will continue the incredible innovation and advancement we have fostered here. I have a keen understanding of the important implications of the Artemis program for our economy, national security, and advancement of technology, but do think we need to evaluate the real challenges of NASA we are facing to achieve their goal in a timely and cost-effective manner.

I'm going to take a little tack away from our typical questioning and get into a little bit of medicine and human physiology in space as a physician. Recently, the U.S. Department of Veterans Affairs (VA) and Walter Reed Army Institute of Research have come together to look at a promising technology known as mitochondrial organelle transplantation to address the mitochondria dysfunction in the neurodegenerative diseases we've seen in human beings but also in astronauts for some reason. We don't even know why. Is NASA aware of the work that the VA—and this is an obscure ques-

tion, so I understand I'm probably talking outside the normal purview. But is NASA aware of this study between the VA and Walter Reed addressing mitochondrial dysfunction? And would they be willing to work toward advancing technology to help these astronauts protect their energy cells if you will?

Ms. KOERNER. So you may or may not know this about me, but one of the interesting career path—parts of my career path is that I spent five years running the Human Health and Performance Directorate at the Johnson Space Center in Houston, Texas. As an engineer running a health and medical organization, I found it very fascinating, and I learned a lot of things about human physiology and how very little we actually understand about the—how the human system responds in a microgravity environment. And we, today, do not understand how the human system would respond in microgravity followed by partial gravity back to microgravity. The longest duration crew member that we have just recently returned last year, and he only spent 371 days in space. When we go to Mars, we're going to have to spend close to 1,000 days in space.

So I recognize that the human as a system is something that we need to investigate and explore further. I also know that we have done a number of studies and a number of investigations with the team that we have at the Johnson Space Center on the exact problem that you indicated. I'm not even going to try to spell it or say it as you so eloquently did because I am not a physician. But I will say that we have made great strides in understanding not only what happens to the astronauts, but what happens to the astronauts and how that can then apply to similar, I'll say, subjects on the ground. And that transferring of that technology and that information has made great strides in a number of medical fields. You can find equipment that we use to—for treating astronauts in an emergency room anywhere in the United States and around the world.

So we do actually partner with them and with others. And I would welcome further conversation on that and putting you in touch with some of the folks that we have that do that work on a regular basis.

Mr. MCCORMICK. I think that is amazing. As matter of fact, if you want to consider somebody who's a pilot and a physician and maybe a Congressman going on one of those missions, just let me know.

Ms. KOERNER. I'll keep that in mind. Thank you.

Mr. MCCORMICK. Dr. Griffin, it's no secret that China has a goal to surpass the United States by 2045. As global leaders in space, we can't allow this to happen. I think the leading edge that we have in space technology will protect the United States in not just the economy, but technologies that can benefit humankind like we just discussed.

As the United States works to recruit additional international partners, how can we in the government continue to promote its vision in space diplomacy over China's? In other words, you can see countries like India putting a vehicle on the dark side of the Moon for about $75 million. Now, granted, it's not manned, so it does cut some corners and they maybe don't have the same bureaucracy re-

quirements, but how can we partner with other countries to make this a more efficient process?

Dr. GRIFFIN. The way we effectively partner with other countries is to establish that we are going to do great things and that there is room for everybody of like mind to join us. We can't partner with people with an empty bag, OK? We have to be clearly seen to be doing things in an efficient, expeditious, focused, determined way. And when that happens, partners will appear.

Mr. MCCORMICK. Great, thanks. And I'll just yield with the statement that this investment is an investment in the future and has great economic and technological benefit to us as we continue to invest in Artemis. Thank you. I yield.

Chairman LUCAS. The gentleman yields back. I recognize my colleague, Ms. Caraveo, for five minutes.

Ms. CARAVEO. Thank you, Chair Lucas and Ranking Member Sorensen, for holding this hearing, and thank you to the witnesses for joining us today.

If there's one State that perhaps unexpectedly is synonymous with the Artemis mission, it's my home State of Colorado. Excuse me. From navigation tools associated with the mission to the Orion capsule itself, Colorado's advanced aerospace infrastructure has been pivotal in the development of these missions. I'm also proud to say that I represent many of the workers and contractors who have made Artemis possible, and I'm excited to continue my support for these missions.

However, I think we have heard a lot of concerns here about the timeline for the Artemis missions. And I think something that we've kind of been beating around the bush about is overall funding for NASA and whether you have the money to carry these missions out.

So, Associate Administrator Koerner, in particular, when we hear today about the pressures that you have to cut costs, to maintain crew safety, to keep things on time, but also, when we have a Congress that has been unable to pass a budget overall, what are the implications for Artemis if NASA is appropriated with flat budgets beyond not just 2024, but potentially the rest of the decade?

Ms. KOERNER. So as I mentioned earlier, we are in production on not only Artemis II, but Artemis III, Artemis IV, Artemis V. We have hardware and builds for all of those missions at various stages, right? So consistency and budget helps us be able to keep the cadence of those missions to where we can keep our team fresh and keep our team active and have them be able to actually produce the hardware in a timely fashion.

We have been challenged by Congress to have an annual cadence of our missions, and if we get stuck in either a flatline or a reduced budget kind of environment, what that means is we will prioritize the near-term missions. Artemis II and Artemis III will be prioritized. And those other missions in the interval between those other missions will continue to push out to the right. It would be my hope that we wouldn't be faced with that kind of a situation, but that's how I would envision that playing out.

I would add, though, resources is more than just budget in my mind. Time is also a resource, but also personnel is a resource. And

one of the benefits of flying these Artemis missions is we inspire the next generation of engineers, of technicians, of welders, of people that can actually do the work, which there's a tremendous shortage of skilled labor in some areas that it's—I'm sure you know, if you've talked to your—for example, some of the contractors that are in your home State, they'll tell you it's sometimes challenging to find the right skill level for building and doing the things that we're trying to do with Artemis. So consistency both in in budget, but also the resources and the inspiration that we can provide to inspire that next individual who can help us build the generation that we're looking forward to building.

Ms. CARAVEO. Thank you so much. Those are very good points. And I think that consistency and budget probably has a direct implication on people being willing to take these jobs. So, Dr. Griffin, in that same kind of vein in your experience, what can the impact of flat budgets and budgetary uncertainty for short-term CRs (continuing resolutions) and shutdown threats, which we've had many of this session, have on the NASA contractor workforce and its ability to meet NASA's needs.

Dr. GRIFFIN. Sorry. In my experience in both DOD and NASA, multiple occasions over the years, it's not so much a flat budget that is a problem. Actually, most of the time I would welcome a flat budget if I knew I was going to have it. It's—it needs to be at an appropriate level to accomplish the task at hand. But flatness in itself is not the issue.

The issue is that when we do not have an appropriation on time, year after year, we force our—the government actually does very little work itself. It may plan and may integrate work, but the work is done by American industry and in some cases our partner industries. And when we cannot—when we stop and start that funding by delaying our—or even skipping our appropriations cycles, as we did in 2008, that is a huge problem.

Ms. CARAVEO. Thank you very much. I yield back the remainder of my time.

Chairman LUCAS. The Chair recognizes the gentleman from California, Mr. Issa, for five minutes.

Mr. ISSA. Thank you, Mr. Chairman.

Over a decade ago, almost two decades ago now, Elon Musk began telling us here on the Capitol and around the country, anywhere someone would listen, that the United States was getting ripped off, that in fact it shouldn't cost more and take longer to take the same basic rocket and drive the same number of pounds into space. Until he got through the almost infinite blockade by the established launch people, nothing happened. Today, we are launching and, in theory, we're launching for less.

But I guess my question is whatever happened to fixed, firm, and fair? Whatever happened to that? I think the question primarily for the IG is, is there any reason that these contracts particularly to go to the Moon and circle it weren't done on a tell us what it'll cost half a century after you already did it?

Mr. SCOTT. Thank you Mr. Issa. As we've previously reported, you know, NASA has been challenged to establish credible costs and schedule estimates. While certainly appropriate——

Mr. ISSA. And they haven't met that challenge. Is that more or less correct?

Mr. SCOTT. Today in the way that we would say is most transparent, that is correct. I think while it's certainly appropriate to have commercial partners involved in the launch activities, a key challenge that we continue to remind the agency it's important to hold them accountable for delivering the promised goods and services at the promised price. You know, we've previously reported that, at times, even though contractors were behind schedule and over cost, NASA was still paying them overly generous performance awards. And so I think, again, this is less about like the "who" and more about just making sure that you hold them accountable for delivering at the price they promised.

Mr. ISSA. Well, a follow up to that, when you've got—I mean, because you're in the business of figuring out the why. Is it because the contractors are not living up to their original promise, perhaps never intended to? Or is a portion of the blame the shifting sands of NASA starting a project and then endlessly changing it even when it's to return to do what you did half a century ago?

Mr. SCOTT. I mean, our work has identified various factors contributing to some of these challenges. You know, one is workforce challenges. It's harder—you know, while you can set a requirement, if you don't have the workforce available at the time to actually execute it, that's challenging.

Mr. ISSA. But——

Mr. SCOTT. Also, NASA's changing requires——

Mr. ISSA. But workforce is a great question. If I'm any of these contractors, either the historic incumbents or the newer combinations, isn't that in the bid?

Mr. SCOTT. There's always optimism that you'll be able to get the workforce to complete the work, right? Some of these contractors are actually competing for the same workers, for example. And again, whether it's workforce issues, whether it's changing requirements on NASA's part, all of those add into these eventual cost overruns that NASA experiences on some of these contracts. Again, this is about accountability for holding the vendors responsible for what they're promising.

Mr. ISSA. OK. Well, I'm going to go back again. When you look at the current cost overruns and time delays, can you pull your slide rule out and figure out why? Or do we have to rely on computers now that cost more and take longer? Sorry, but I can't resist the fact that we truly did go to the Moon with slide rules, and we now seem to be—take longer with more indecision when we're simply retracing the steps. Perhaps it's because we're not measuring with a slide rule.

Mr. SCOTT. Our work previously talked about some of the challenges NASA faced with project management. Part of it was overoptimism, right? NASA can get things done. Sometimes that confidence in getting things done so overrules what you know it's going to take to actually get it done. Part of it is—and Cathy spoke to this earlier—the unstable funding stream, right, it's hard to plan in the long term if you're not sure about your funding stream in the near term. And finally, sort of making sure you continue to grow the workforce within NASA and within the industry to con-

tinue to support the work you're doing. So there are a number of challenges to NASA being able to get these projects done on time and at the promised amount.

Mr. ISSA. Well, if we assume for a moment that Congress isn't going to change, we assume for a moment that the Moon isn't moving differently than it did half a century ago, what should we demand that NASA do in order to deliver the rest of Artemis II and III on time and with no greater overruns than we've already experienced? What would be the steps that Congress would be required to take?

Mr. SCOTT. In my view, one would be locking the agency down into making lifecycle cost and schedule commitments. We understand that the world is complex, things will change, but it's incredibly important for Congress to at least have an initial idea of what it's going to cost and when NASA can get it done.

Mr. ISSA. I thank you. The questions could go on again and again, but I probably really would have to bring a slide rule if I were going to calculate all the overruns. So with that, I yield back, Mr. Chairman.

Chairman LUCAS. It would be fascinating watching you use a slide ruler.

Mr. ISSA. I've got a whole bunch in my collection if you want me to bring it in.

Chairman LUCAS. Not a doubt in my mind, not a doubt at all in my mind.

The Chair now recognizes the—Congresswoman Lee for five minutes.

Ms. LEE. Thank you, Mr. Chairman and Ranking Member, for holding this important meeting.

Serving in this office for over a year now has been a unique experience learning more about the scientific communities and the ways I can serve my constituents beyond the personal passions that drove me to serve in western Pennsylvania. Recent inclement weather across the country has affected us all in one way or another, but space science particularly through the use of satellites is crucial for meteorologists like yourself, Mr. Sorensen, to make more accurate and timely weather predictions, ultimately improving our ability to respond to and mitigate the impact of various weather events.

While we continue to race to the Moon and all the discoveries that we may uncover there, I continue to look toward the research and work of countless scientists here on Earth and 1,000 miles above that will help innovate our approach toward realizing things like cleaner air and water, sustainable infrastructure, and more equitable transportation in southwest PA and across the Nation.

Today, we've discussed what path forward entails and returning men and hopefully landing our first woman on the Moon. In this arena, just as in life, the concept of failure is an essential step in the pathway to success. I'm proud to represent Astrobotic in Pittsburgh, who, for the last 16 years, has worked tirelessly to make returning Americans to the Moon surface a reality. While last week's unfortunate anomaly with the Peregrine lunar landing reaffirms the unforgiving nature of the space environment. It also further highlights that success—the success that we can achieve through

the pursuit of innovation and pushing boundaries. Between the lander's launch and its expected reentry to Earth's atmosphere tomorrow, the vehicle's flight has provided irreplaceable knowledge, experience, and insight that will feed forward into making Artemis and the U.S.'s return to the Moon a sustained success.

Onboard flight systems like avionics, propulsion controllers, thermal control systems, and more have been tested and qualified, creating new capability in the U.S. space industrial base that could be utilized for other missions and programs in the future. So I'd say now is not the time to retreat. Our Nation has consistently, throughout its history, built upon our ability to adapt and respond to failures, and we must continue to support CLPS efforts so the Nation gets the benefit of hard-earned lessons learned from the missions—that mission and others like it.

Ms. Koerner, while setbacks are often inevitable in science and in life, commercial space industry leaders like Astrobotic find a measurable value and constancy of purpose and programs critical to the Artemis mission. Why is it critical for the Nation to keep supporting missions like those on Commercial Lunar Payload Services (CLPS), despite the challenges?

Ms. KOERNER. So part of our charter is also to develop an economic engine that generates and stimulates activity in the space sector. And so what we've been doing with the Commercial Lunar Payload Services contract—and we call it CLPS. I think you referred to it as C-L-P-S.

Ms. LEE. Oh, CLPS.

Ms. KOERNER. CLPS——

Ms. LEE. I'll do that one next.

Ms. KOERNER. CLPS is the way we refer to that—is one of those opportunities to help spur on the development of new space entrants. We know that there's a lot of space industry and the big names that have been out there for years, and they do contribute tremendously to the Artemis program. But we want to also make the entrance bar lower so that we can more broadly generate economic activity across the board. Plus, we find a lot more innovation in some of these commercial providers.

It was disappointing that the CLPS provider had challenges last week, but we did still get tremendous data. And we will continue to get data from CLPS missions as we launch those as precursors. It's really important for us to have robotic precursor missions because that gives us data that helps inform and enable, and it makes our mission safer. What we discovered and what they learned very, very much so last week, but what we have discovered over a number of tragedies is that space and space exploration is unforgiving.

And what we are doing with Artemis is infinitely safer than what we did in the Mercury, Gemini, and Apollo days. In just recently talking to one of the first flight directors from that era, he told me that he didn't realize until more recently just how close they were to having a national tragedy during a number of those Apollo missions. And that's because they were just young, and they didn't understand what they didn't know. We're a lot smarter now with the missions that we've flown and with the sacrifices that

we've made, and so every step that we make with Artemis makes us safer as we explore.

Ms. LEE. Thank you. That's my time. So I will yield back now instead of launching into another question, but I appreciate you all for coming today and for sharing your testimony.

Chairman LUCAS. The gentlelady yields back.

I would note to the witnesses that we're still 40 minutes away from noon, and after consultation with the Ranking Member, I believe we'll do another round, conscious of your time.

Associate Director, let's go back for a moment to that measure contractor performance discussion. You talked about the incentives if contractors produce ahead of schedule, on time, and I think the carrot is always very important. Let's discuss for just a moment the stick. What are the consequences for contractors if they don't meet the milestones by the assigned deadline?

Ms. KOERNER. So again, it depends on the type of contract, right, that we have. We have performance awards that we can decrement associated with not meeting milestones. For firm fixed price contracts, it depends again on the way the contract's written. They have to perform, and in some cases we have penalties if they perform—they have to reimburse the U.S. Government for the cost. And by reimburse, I say it basically decrements the payment that they would get in that milestone payment. So they may not, for example, get all of a milestone payment if they don't meet in a timely fashion.

So again, it depends on the contract mechanism what penalties that we can put in place, but we also have ways that we can reflect the contractor performance in a more broad scale to the rest of the community, so it does affect their ultimate bottom line.

Chairman LUCAS. So speaking of the milestones, for instance, have any of the milestones been divided up into interim milestones, or have interim milestones been created to allow for earlier payments? I ask because this data would be helpful in providing insight into program progress.

Ms. KOERNER. So I'm not entirely sure I understand the question. We do break certain milestones up and, for example—and I can speak to the experience I had managing the Commercial Resupply Services contract for the International Space Station years ago. If we got to a milestone, and we felt like the contractor didn't do all the things or completely meet the milestone in a timely fashion, we would withhold a certain amount of that award. That's what I mean by decrement. So instead of them getting X, they would get X minus a certain amount. And we did that based, again, on the value judgment for what that milestone was worth. And then they had an opportunity in some cases—not in all. Some cases, that was just money that came back to the program. But in some cases, we would defer the payment until they accomplished it in the manner in which we needed. And there were plenty of opportunities that we got from them. And I'll say in-kind work and additional work and benefit to the U.S. Government that was performed as a result of them, for example, being late on some of those milestones.

Chairman LUCAS. Because I think sometimes we get questions from appropriators and other oversight entities that perhaps the

milestones should be—of course, should be designed to accomplish the work in an efficient and effective fashion and accelerate if helpful, but that the milestones not be designed just to help the contractor move along——

Ms. KOERNER. No, they——

Chairman LUCAS [continuing]. Through the process.

Ms. KOERNER. They certainly are designed, I'd say, mutually. So when—a lot of times when we award these, especially the firm fixed price contracts, the contractor will propose to the U.S. Government what they would like to see in the milestones. And as part of the negotiation before we even award that contract, we will adjust those milestones, but the values, but the timing of them also in order to make sure that it meets the timeline that we need for whatever it is that that contractor is providing.

Chairman LUCAS. Speaking of the international element of all these efforts, again to you, Associate Director, NASA recently announced a partnership with the UAE on Gateway under which the Mohammed bin Rashid Space Center would provide Gateway's crew and science airlock module, as well as a UAE astronaut to fly to the lunar space station on a future Artemis flight. How will NASA and UAE share costs related to this partnership?

Ms. KOERNER. So I don't know that we—I would say we share costs, right? So when we negotiate with an international partner for a contribution to Artemis or to any activity, there is a—I'll say a value that we assess, that we, the U.S. Government, assess on the—on what they are contributing, and then in kind we return a value to them. So for example, the one that you mentioned there, the UAE will be providing the airlock, and in exchange, we, NASA, are going to be training a crew member and launching a crew member and giving that country an opportunity to have a crew member on the Gateway space station. So it's more of a value-to-value contribution as opposed to a cost.

Chairman LUCAS. By the way, is the UAE providing airlock on the Gateway a critical path, an important part——

Ms. KOERNER. Absolutely——

Chairman LUCAS [continuing]. Of the concept?

Ms. KOERNER. It absolutely is critical. So it enables us to have access both internal as well as now external access to scientific payloads that we can put on the exterior of Gateway and enables us to be able to do maintenance on the Gateway. Having an airlock provides more flexibility for how we use the Gateway space station in cislunar orbit for future missions. I spoke to it earlier when I talked about the flexibility in our missions. Having different elements of the Artemis program enables us to have that mission flexibility.

Chairman LUCAS. Ranking Member, humor me for one more question. The UAE is of course an example of international partnership. They have resources with which to work, which is critically important. But I ask this question in the context of the technology. They also have a history of partnering with China in lunar efforts. For instance, the same entity has an agreement to include a rover on the Chinese mission to the lunar south pole. I guess my question is how—when we are partnering with people who are partnering with others, how do we ensure that the technology

shared through a partnership doesn't, shall we say, inadvertently contribute to someone else's space capacities?

Ms. KOERNER. So we have a fairly rigorous export control process that monitors and manages our interactions with our international partners at every level to ensure that exactly what you just said does not happen.

Chairman LUCAS. My time has expired.

I recognize gentleman Mr. Sorensen for five more minutes.

Mr. SORENSEN. In my opening statements, I had mentioned how important it was to bring a NASA astronaut to my district. Dr. Kate Rubins has been back and forth to the International Space Station several times. And one of the simple problems that she discussed with me and with the students in my district as we were going to schools was that spacesuits were designed for men. They weren't designed for women. And that was something that she had to deal with in real time.

And so that brings me to another line of questioning for Mr. Russell. GAO's recent report on Artemis programs noted challenges with developing and testing the exploration spacesuit. Can you discuss these challenges and what measures can NASA take to help address such challenges, including issues that we have with the supply chain?

Mr. RUSSELL. Certainly. Thank you for the question. I think the first challenge to note was, originally, NASA designed the spacesuit in-house, and then made the decision to contract that out, which is happening now. As we took a look at some of the current challenges, certainly one has to do with sufficient life support. You need to have backup as you're doing lunar operations, have confidence that the system can operate and sustain the astronaut's life as they go through the mission. So there are some technologies that need to be matured there, some refinements to the requirements that the contractor is working on. That's some of the key things that we pointed to in our recent report.

Mr. SORENSEN. Ms. Koerner, I'd like to go a little bit more in depth on that. Could you talk about the significant work that is needed to mature technologies for the exploration spacesuit life support systems, as Mr. Russell was talking about. Are the spacesuits on the critical path for Artemis III? Does NASA have the roadmap for how spacesuit life support systems will be matured and then maintained?

Ms. KOERNER. So, as was noted, NASA designed the spacesuit and gave this—made that design available to U.S. industry to be able to produce. And one of our spacesuit providers is using that design. We have a long history of doing space walks and developing spacesuits but also managing spacesuits and managing those systems. I think it's obvious, but I just want to make sure it's very—I state it very clearly. A spacesuit is like a personal spacecraft. And it's very complex. It has all of this same kinds of systems that a spacecraft would have but in a much smaller environment. And it has to be, as you noted, adaptable for both male and female of various sizes and shapes.

So the design and the development of the hardware for that is something that while NASA has experience on, we're trying to foster that experience in our commercial industry partners and are

helping them. One of the ways we do that is through government task agreements, and we are enabling their development and helping them with some of that testing through those government task agreements. So it really is a partnership activity. Even though it is a service contract and they are doing the development of the exploration suit, NASA is standing side by side with them and enabling that to happen.

Mr. SORENSEN. Do you—and I'll open this to anyone who wants to answer. Are there other opportunities for public-private partnership that we haven't yet—done yet, for instance, with spacesuits, to open that up to companies to be able to come up with a technology to learn? Are there other ways as we look forward to Artemis II and Artemis III that we can look forward to that?

Ms. KOERNER. So I'll offer that there's plenty of opportunity, I would say, for partnerships and for on-ramping new technologies, not just in spacesuits, but in every aspect of what we're doing with Artemis. One of the things that we've done over the last couple of years is we established a process for our architecture, which is the entirety of our plan for exploration that does an annual review where our entire organization, all of NASA, all of our mission directorates, all of our technical authorities, all of our centers all get to weigh in on the path that NASA is moving forward on. And we get to share the technologies that are developed in industry and onramp those. We share the output from that review with industry, and we have a constant and regular dialog with industry, with our international partners, with academia, to do just that, to identify opportunities for partnerships, but also to make sure that what we're doing with our exploration activities aligns with the direction that our stakeholders want us to go.

Mr. SORENSEN. Great. So we're on the right path for Artemis——

Ms. KOERNER. I believe we are.

Dr. GRIFFIN. I would——

Mr. SORENSEN. Thank you.

Dr. GRIFFIN. If I might add?

Mr. SORENSEN. Yes, sir.

Dr. GRIFFIN. I would add that if the United States and its international partners have a consistent program to return to the Moon and stay, that there are an enormous number of infrastructure development opportunities available in which commercial industry can invest because they know that there will be a return. So I mentioned communications, navigation functions earlier, command and data handling, data storage. The CLPS program was brought up. There will be a need in supplying a human lunar base for all types of cargo ranging from small, high-value items to bulk cargo that industry could supply if they know that there is going to be a consistent market for such.

Mr. SORENSEN. And I think that's an important part is we're not just going back to the Moon. We're going back to the Moon to stay on the Moon.

Mr. RUSSELL. I would hope so, although I've been trying for over 30 years to promote such an activity and have so far failed, so I possibly should retire from the field.

Mr. SORENSEN. No, don't do that. I yield back.

Chairman LUCAS. The gentleman yields back. You never give up. Speaking of never giving up, I recognize the gentleman from California for five minutes.

Mr. ISSA. Thank you, Mr. Chairman.

Associate Director, you talked about reducing the mortality or potential mortality? We've lost 15 astronauts over the years. I guess my question is, what statistic or fact would show that we've become safer over time in space?

Ms. KOERNER. So I don't know that I can point to a single statistic, but what I will tell you is that we have more redundancy in our systems. We have more reliability in our systems. We have more capability in our systems. And I think that alone gives us a greater confidence that even though we're doing something that is extremely, as I said earlier, unforgiving, that we have more safeguards and safety in the system.

Mr. ISSA. I understand, but today, we're talking—we're looking at significant delays in doing something that we did before. Nobody died going to the Moon and back. As a matter of fact, the program that killed most of our astronauts was the cost-saving, redundant-use, new and improved shuttle. Ultimately, that program killed the majority of all astronauts that ever died. The early exploration had its death, including three on the ground. We learned from that, don't sit in a bag of oxygen on the ground, not able to get off the ship quickly.

So there have been lessons. But I'm—you know, I've listened for quite a while to this discussion about the spacesuit and, you know, what we're going to do and the discussion as though that women were new to space. I'm sorry, but we've had women in space for longer than some Members of Congress have lived now. So I—I'll ask again. We're looking at overruns and delays.

And so I think I'll go to Mr. Russell. When they're putting that figure out there—we've had—2.9 percent of all those who have gone to space have died, so it's not an insignificant number. But if you take away two events of a single program type, you suddenly go from nearly 700 flights and 19 dead to almost nobody in the rest of those flights.

So when we're looking at the cost and delivery, are we in fact looking at Artemis—looking for new solutions to things which have already been solved? You know, I'm from the generation of the joke about the difference between our inverted writing instrument and the Russians, OK? And for those who haven't seen it, exactly, we came up with the space pen, it cost millions. They came up with a pencil. And for redundancy, they had a second one.

So again, as we're looking at firm fixed pricing and predictability of time, should we in fact push NASA to accomplish the mission with the highest level of reuse of technology, or should we allow them to continue to say, but we're exploring all kinds of new technology, which inherently brings in—at least in my examination, it brings in risk assessment of new technology? One only needs to look at the Boeing MAX and ask the question, is there anything that new about a 737 going 34,000 feet? No. But somehow, every change is a variable.

So if we're looking to deliver on time, on budget, are we doing all the right things, or are we doing all the things that have led us to this inevitable delay and cost overrun?

Mr. RUSSELL. Great question. I think that's the—as I see it, NASA is at an inflection point right now because they are about to set the agency baseline commitments for a number of these efforts. And you referred to the firm fixed price contracts and things. And once you settle on a number that is great, you can hold the contractor to that price, that deliverable, but it's up to the government to have stable requirements, right? When you change those requirements, then that changes the deal that you have with the contractor that could cost additional funds.

So right now, what we expect to see is really——

Mr. ISSA. Contract changes are where all the profit is, isn't it?

Mr. RUSSELL. Right, that equals dollars. If it's a cost-plus contract, you know, if there's a delay, you're paying the contractors cost plus whatever fee goes along with that.

So I think as we look to these new efforts, how those technical and cost baselines are set and the realism of those are going to be very important. And we'll see in the coming 12 to 18 months whether the projects can adhere to those baselines, meet the technical challenges. There's going to be some margin for cost and schedule reserves to deal with issues, but the fidelity and the realism of those baselines will be extremely important for what are some new and novel technologies. A lot of these systems, you know, it's not just a rocket, it has a payload. That's never been done before. There's a lot of firsts. The way that the HLS system will work with, you know, essentially a gas station in space that will, you know, fill up the lander and help accomplish the mission, all of those are new and novel things. So capturing that technical risk, putting it in a realistic baseline, I think, will be essential.

Mr. ISSA. Thank you. Thank you, Mr. Chairman. I yield back.

Chairman LUCAS. The gentleman yields back.

Seeing no additional questions, I want to thank the witnesses for their valuable testimony and the Members for your questions. We will have more of these hearings and expect, with a different attitude from Mother Nature, a really big crowd.

The record will remain open for 10 days for additional comments and written questions from the Members. This hearing is adjourned.

[Whereupon, at 11:38 a.m., the Subcommittee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Ms. Catherine Koerner

1

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Returning to the Moon: Keeping Artemis on Track"

Ms. Catherine Koerner, Associate Administrator, Exploration Systems Development Mission Directorate, National Aeronautics and Space Administration

Questions submitted by Chairman Brian Babin

1. **In 2019, as a priority recommendation, GAO urged NASA to develop a life-cycle cost estimate for Artemis 3, in order to provide Congress with insight into the mission's affordability. The GAO website still lists this recommendation as open. NASA initially stated that it would establish cost and schedule commitments for projects, but not the Artemis 3 mission overall. In February 2023, NASA indicated that it would develop a methodology to provide Congress with an assessment of each Artemis mission's costs, but it did not provide a time frame for this. What is the status of the development of a process for creating life-cycle cost estimates for individual Artemis missions and when do you expect it will be completed?**

   Response: Artemis implementation is unique from other NASA activities in that the flexible architecture is a guiding principle within the Artemis program, 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. These developments are consistent with NASA policy and follow the development process as documented in NASA command media (i.e., NASA Procedural Requirements 7120.5). NASA recognizes GAO's critical role in promoting Artemis accountability and transparency; however, imposing a flight-by-flight cost assessment would require a somewhat arbitrary division of costs because the program is not managed, budgeted, or operated in a flight-by-flight manner.

   NASA utilizes a range of management and reporting tools that provide cost and schedule information to stakeholders. These tools include project-level cost and schedule joint confidence level informed development commitments (including for major developmental upgrades), independent review at major life cycle reviews and associated key decision points, documented and configuration-controlled mission definition baselines, by-mission schedule risk assessments, life cycle cost estimates in Phase E, five-year rolling estimates consistent with guidance provided in 7120.5F, annual Agency budget requests, Agency-led baseline performance and major program reviews, independent reviews by the NASA Advisory Council and Aerospace Safety Advisory Panel, and multiple ongoing reviews from the governmental oversight entities. The Agency will request closure of this recommendation.

2. **The GAO has previously reported that a lack of cost and schedule baselines contributes to poor acquisition performance. NASA programs set cost and schedule baselines through launch, or a key schedule milestone that marks the end of development. Some of the large NASA programs that are entering operations, such as the Space Launch System and Exploration Ground Systems, are continuing to make large procurements or facility**

modifications to support future Artemis missions. How is NASA tracking costs for development activities that occur after an initial key schedule milestone?

Response: NASA utilizes a range of management and reporting tools. These tools include independent review at major life cycle reviews and associated key decision points, documented and configuration-controlled mission definition baselines, by-mission schedule risk assessments, life cycle cost estimates in Phase E, five-year rolling estimates consistent with guidance provided in 7120.5F, Agency-led baseline performance and major program reviews, independent reviews by the NASA Advisory Council and Aerospace Safety Advisory Panel, and multiple ongoing reviews from the Office of Inspector General and Government Accountability Office.

In October 2023, a separate Agency Baseline Commitment (ABC) was established for the Space Launch System (SLS) Exploration Upper Stage and its associated capabilities upgrades supporting Block 1B, currently slated for Artemis IV. In April 2024, the Exploration Ground Systems (EGS) program established an Agency baseline commitment for cost and schedule for the Mobile Launcher 2.

3. NASA's Artemis missions require numerous complex programs to complete parallel development work and ultimately be seamlessly integrated. In 2022, the Aerospace Safety Advisory Panel reported that an unprecedented mix of acquisition approaches with asynchronous delivery time horizons presents risk management challenges. Integrated risk and schedule management are critical endeavors. How is NASA integrating risk management across the Artemis enterprise? And, how is NASA mitigating cost, schedule, and technical risk that may arise due to cross-program dependencies?

Response: The fundamental responsibility of the Moon to Mars (M2M) organization, at all levels, is the active, integrated management of risks to the Artemis campaign through the deep embedding of risk-based decision-making throughout the enterprise. M2M broadly defines risk management as the control of known and potential risks to the M2M technical, operational, or programmatic baseline, including but not limited to risks held in the programs and M2M risk management systems, hazards, concerns, watch items, liens, and threats. The M2M baseline includes Level 1 requirements, technical performance measures, mission definition baselines, manifests, budgets, and other parameters as defined and controlled by the Deputy Associate Administrator (DAA) for M2M.

Risk management is an integral part of the mission and phased-based integration approach that M2M has implemented for delegation of responsibilities to the programs. Delegation of M2M baseline implementation (including risk acceptance) flows from the M2M DAA to the programs and other organizations within M2M consistent with the M2M governance model. All levels of the M2M organization are responsible for actively identifying and effectively communicating known or potential risks to the M2M baseline. M2M programs and M2M Program Office divisions are responsible for managing and mitigating risks within their delegated areas of responsibility, including explicitly identifying risks and risk mitigations in decision packages that come before program and M2M control board processes. Risks that exceed the authority delegated to a program and/or M2M Program Office integration division are elevated to the M2M DAA (and, if necessary, to the Mission Directorate, or Agency level) for final adjudication and risk acceptance.

a. **Follow-up: Has the Moon to Mars office implemented the requirements dictated for that office in the 2022 NASA Authorization Act, including the requirement for a Director who is accountable for risk management and has authority to manage resources and Moon to Mars-wide systems engineering and integration?**

Response: Yes. In March 2023, per direction in the 2022 NASA Authorization Act, NASA established the Moon to Mars Program Office at NASA Headquarters, under Deputy Associate Administrator Amit Kshatriya. As directed by the legislation, the Moon to Mars Program Office focuses on hardware development, mission integration, and risk management functions for programs critical to the agency's exploration approach that uses Artemis missions at the Moon to open a new era of scientific discovery and prepare for human missions to Mars. This includes the Space Launch System rocket, Orion spacecraft, supporting ground systems, human landing systems, spacesuits, Gateway, and more related to deep space exploration. The office also leads planning and analysis for long-lead developments to support human Mars missions.

4. **In a November 2023 report, the GAO noted that "NASA documentation states that SpaceX has made limited progress maturing the technologies needed to support [their Human Landing System] plan." Additionally, earlier this month, the Human Landing System, or HLS, was cited as one of the motivators for the delays that were announced to Artemis 2 and Artemis 3. Can you provide a status update on HLS development as well as an estimate of when SpaceX's HLS will be ready for Artemis 3?**

Response: SpaceX is making significant progress in the development of the HLS Starship, which will transport astronauts to the lunar surface during Artemis III and Artemis IV. In 2023, (April and November 2023), SpaceX conducted two flight tests of the integrated Starship-Super Heavy launch vehicle system. Although both tests ended in mishaps, the root causes were identified and corrective actions implemented, resulting in substantial improvement from Flight 1 to Flight 2 in the performance of both the vehicle and the ground systems at SpaceX's launch site in Boca Chica, Texas. A third flight test was conducted in March 2024 where Starship lost contact with Starlink and the Tracking and Data Relay Satellite System upon reentry, resulting in the boosters not successfully splashing down in the Indian Ocean as planned after the engines on the booster did not ignite properly. Additionally, major HLS Starship advances for Artemis III over the last year included completion of an Environmental Control and Life Support System (ECLSS) ground test, a Gaseous Propulsion Module demonstration, and a Docking Adapter test and qualification review. NASA and SpaceX are planning an in-space demonstration of HLS Starship cryogenic propellant storage and transfer by the Spring of 2025 and a Critical Design Review for the lander by the Summer of 2025. For the Artemis IV variant of HLS Starship, SpaceX completed a Certification Baseline Review last summer, which confirmed that the design specifications are responsive to NASA requirements.

Per NASA's January 9, 2024, announcement of updates to the Artemis campaign, the Agency is targeting crew launch for the Artemis III mission in September 2026. To support this schedule, NASA and SpaceX are planning the HLS Starship launch to occur in the spring or summer of 2026.

Blue Origin has also made significant progress since NASA selected them last year to develop the HLS Blue Moon lander for Artemis V, completing its Certification Baseline Review in December 2023. NASA and Blue Origin completed a Preliminary Design Review of their lander in March 2024.

5. **In September 2022, GAO released a report which recommended that NASA "develops guidance that identifies a regular and recurring process for long-term Artemis workforce scenario planning to address future uncertainties, at least 5 years beyond the existing 5-year workforce plans." In justifying the recommendation, GAO noted that the lack of a longer-term workforce plan creates uncertainty for existing Artemis contracts which extend beyond the current workforce planning scope. While NASA has agreed with the recommendation and indicated they are developing a plan, the GAO website still lists it as an open recommendation. Can you provide an update on NASA's progress in developing a process for long-term Artemis workforce scenario planning?**

   Response: NASA's Policy Directive on Strategic Workforce Planning was published in February 2022 and established NASA's three strategic workforce planning interests. These interests are to 1) Create agility in the workforce, 2) Become more demand versus supply driven to respond to changes in the mission, and 3) Strategically shape the workforce to meet both near- and long-term goals and objectives. In the winter of 2022-2023 the NASA Mission Directorates (MD) drafted guidance that provided additional information, particularly addressing long term plans, beyond what is in the one-year budget submission to support conversations regarding outyear workforce planning. This was released to the NASA Centers in February 2023. In April 2023, all NASA Centers provided initial analysis of long-term MD plans in terms of impacts to local workforce and addressed any change of workforce strategy if needed. NASA will continue to conduct this workforce analysis annually to effectively respond to both known and uncertain mission demand and strategically shaped to provide the mix of skills to support NASA's unique work roles. NASA formally submitted our response to GAO in summer 2023, meeting GAOs requirements.

6. **Can you describe how NASA will select the crew members for missions beyond Artemis 2? How is NASA ensuring astronauts are selected through a transparent and merit-based process? Do the GAO and the NASA IG have insight into this process?**

   Response: For the safety of the crew and success of the mission, NASA assigns its crew members to missions based on requirements once detailed mission needs are determined. NASA's Chief of the Astronaut Office is responsible for crew assignments. The Chief of the Astronaut Office, who is selected and appointed by Flight Operations Directorate (FOD) and Johnson Space Center (JSC) leadership, makes decisions about crew assignments for space flight missions with concurrence from the directors of FOD and JSC. Given the small size of the astronaut corps, the Chief and Deputy Chief of the Astronaut Office are knowledgeable of the corps' experience, interpersonal skills, and training to make crew assignment decisions. The Chief of the Astronaut Office receives feedback from other astronaut office personnel such as branch chiefs on proposed assignments. The crew assignment process varies in length and considers multiple factors, such as the upcoming flights requiring a crew, timing necessary for training to be completed, availability of crew currently assigned and unassigned, technical requirements of the mission, and the skillsets of available crew. Through the established process, NASA will ensure future astronaut selections are transparent and merit-based.

7. **NASA recently issued a memorandum reorganizing Center and Headquarter program management responsibilities and authorities. Can you explain how this new process will work, and how it will ensure that Center technical, programmatic, and safety expertise will be preserved?**

Response: Formal reporting for ESDMD Program Managers (PMs) is moved to the HQ M2M Program Manager, consistent with congressional mandate to align accountability, risk management, and authority in the M2M Program. The six PMs – for Exploration Ground Systems, Space Launch System, Orion, Human Lander System, Gateway, and Extravehicular Activity and Human Surface Mobility – now report to the M2M Program Manager consistent with an agency decision that all Category 1 PMs will report to Headquarters instead of Centers. Center Directors will maintain Technical Authority.

NASA will use existing Center Director/Mission Directorate forums to address culture, development, and succession planning. Center leadership will be included in succession planning discussions. The Mission Directorate is responsible and accountable for selection of PMs, in consultation with the Center Director.

PMs will continue to attend Center Senior Staff Meetings to ensure connectivity to Centers. ESDMD PMs continue to communicate through the M2M Program Manager and associated forums including skip-level meetings between AA and PMs.

Each Center has a role and responsibility in delivering products, and there is an expectation for PMs to continue full technical and programmatic integration with Centers and to maintain open dialogue on program challenges and updates. Finally, PMs have a responsibility to engage in discussions with the Center when they are coming to an end of use for a facility/infrastructure.

8. **Has NASA accounted for the infrastructure upgrades needed to support both Starship and HLS launches?**

Response: SpaceX's Boca Chica launch site infrastructure supported two Starship test flights in 2023, and several more flights are expected to be conducted this year in addition to the March test flight. To enable the in-space demonstration of HLS Starship cryogenic propellant transfer by the Spring of 2025, SpaceX plans to develop a second orbital launch pad at Boca Chica. This will allow two Starships to be launched in rapid succession to support the demonstration. Beginning with an uncrewed lunar landing test to be conducted by the Fall of 2025, NASA and SpaceX are planning to start using new Starship launch infrastructure at Kennedy Space Center's Launch Complex 39A (LC-39A) in addition to Boca Chica. This test will require the launch of a Starship propellant depot, multiple Starship tankers, and an HLS Starship. SpaceX's operational plan is to execute some of these launches from Boca Chica and some from KSC/LC-39A. Similarly, the delivery of the HLS Starship to lunar orbit for Artemis III will require multiple launches, some of which are planned to be executed from Boca Chica and some from KSC/LC-39A. NASA and SpaceX have been coordinating on the plans and schedule for implementing all required upgrades at KSC, in accordance with a NASA-SpaceX property agreement for use of LC-39A.

Questions submitted by Ranking Member Eric Sorensen

1. **During the question-and-answer portion of the hearing, in response to my question about communicating the risk of the Artemis missions to the public, you noted that "safety was of the utmost importance" in the decision to delay the launch date of Artemis II.**

    a. **Beyond the communication of launch delays, how is NASA planning to communicate the risk of the first human lunar landing in over 50 years, Artemis III, to the American public?**

    Response: The risk to each mission is communicated via numerous paths.

    Specific technical risks associated with a mission are reported in the runup to a particular flight. NASA holds pre-mission Flight Readiness Reviews and holds press conferences where the agency describes the relevant risks and how those risks are dispositioned.

    b. **What is the approach that NASA is taking to calculate end-to-end risk for the Artemis III mission?**

    Response: There are four primary assessments that NASA uses to assess the safety of any missions. Three of these are qualitative in nature and the fourth is quantitative. The four are used and compared against each other to ensure completeness.

    1. Hazard Analysis: This is an assessment identifying all the possible catastrophic events for a given mission. For each cause that can lead to a catastrophic hazard, control strategies to prevent the hazards are identified, codified into requirements, and verified through rigorous engineering analysis and processes.

    2. Failure Modes and Effects Analysis (FMEA): FMEA is an analysis that looks at failures that can occur strictly from a hardware standpoint (bottom-up) and identifies the effects of each failure. In this analysis, the effects of failures are traced to the impact those failures can have at the component level all the way up to the overall integrated system level. The analysis also identifies mitigations to the failures and demonstrated hardware redundancy. It is a complementary analysis to the hazard analysis.

    3. Crew Survival: Crew Survival Analysis considers the additional capability to provide crew survival if all hazard controls (from item 1) have failed. Emergency Systems such as fire extinguishers, life jackets, and emergency breathing masks are examples of crew survival methods.

    4. Probabilistic Risk Assessment (PRA): PRA is a quantitative risk model of the mission. It uses a model of the system and mission and assigns probabilities to system and other failures that may result in loss of crew (catastrophic hazards). The result is calculated in a numerical mean

probability of loss of crew. This assessment captures those things that we know about and can mathematically model.

In addition to the Safety and Mission Assurance Analyses that are identified above, there is a healthy Risk Management approach that identifies potential and realized threats to the Artemis III baseline mission. For each of the identified threats to the baseline and technical, cost, schedule, and safety risks considered, mitigation plans are developed to minimize the impact to the baseline and resultant risk increases. By actively managing the identified risks in the context of the end-to-end mission risk, focus can be placed on the highest risks and those likely to be mitigated most effectively. This has a net effect of driving the Artemis III mission to be as close to the agreed Risk Baseline as possible.

c. How does the approach identified in (b) compare to the risk assessment approach for Apollo 11?

Response: The risk assessment approach for Artemis has its roots in the Apollo program but has matured significantly given experience on Apollo and human spaceflight programs since that time. Since Apollo predated many of the modern computational tools and other technological and materials advances engineers are using on Artemis, engineers in the Apollo era relied on higher levels of engineering margin and relied primarily on reliability analysis and probabilistic risk assessments. Apollo engineers had reliability requirements on the hardware and used a combination of testing and analysis to show compliance with those requirements. This analysis was focused solely on the reliability of the hardware through understanding of the failure modes. They understood the need to have a way of aborting from the Saturn V and a few other abort scenarios, however these were basic and based on engineering judgment and lessons learned for their test program.

d. What values will NASA require the provider of a human landing system to meet for the risk metrics of probability of loss of crew (LOC) and probability of loss of mission (LOM) for an individual Artemis crewed landing mission?

Response: The HLS program has two requirements for HLS contractors in the HLS Program System Requirements Document (PSRD):

- The HLS Loss of Mission (LOM) probability distribution for a Lunar sortie mission shall have a mean value of no greater than 1 in 10 for the mission.

- The HLS Loss of Crew (LOC) probability distribution for the Lunar sortie mission shall have a mean value of no greater than 1 in 75.

These are NASA level requirements that will be verified by a NASA probabilistic risk assessment (PRA), addressing both lunar sortie LOM and LOC. A significant input into this HLS PRA is the contractor's reliability requirement:

- The HLS shall have a minimum system hardware reliability of 0.975 for an eight (8) Earth-day sortie mission to the lunar surface including at least two (threshold) and five (goal) Lunar surface EVAs, without corrective repair for the entire sortie.

NASA works with the contractors during the Design Development Test and Evaluation (DDT&E) phase to mature the HLS PRA. The PRA also is used as feedback into design trade studies as top risk drivers are identified.

2. **NASA has awarded a contract for the Human Landing System (HLS) initial capability to land astronauts on the Moon during the Artemis III mission, and, according to the Government Accountability Office (GAO), "the HLS program is proceeding with development without formal approval of a cost and schedule baseline," as stated in the November 2023 report, "NASA Artemis Programs: Crewed Moon Landing Faces Multiple Challenges." Please explain how the Human Landing System initial capability is complying with Section 30104 of title 51, U.S. Code or any deviations.**

Response: In November 2023, the Agency approved a cost and schedule baseline permitting the HLS Program Initial Capability to enter Phase C of the life cycle. For Key Decision Point - C (KDP-C) the HLS program established a cost and schedule baseline pursuant to P.L. 109-155.

3. **GAO's report on NASA's Artemis programs that was released in December 2023 highlighted lunar dust contamination as having potential risks for Artemis crew and hardware systems. Please explain the nature of the risk of lunar dust contamination to Artemis programs and what steps NASA is taking to understand and mitigate such risks.**

Response: For Artemis lunar surface missions, NASA plans and designs for operating in a lunar dust/regolith environment in the Moon's South Pole region. Dust interaction with hardware during surface operation can degrade hardware performance. Dust adherence on crew suits and hardware can bring dust into the habitable volumes and impact the crew's operating environment and health. Therefore, dust is an external lunar surface and internal habitable volume concern.

Historical Apollo missions provided NASA's first glimpse into the impact of dust in both the external and internal operating environments. Applying Apollo lessons learned, Artemis will also have the advantage of research on the impact of dust on crew health. NASA developed a large database of crew health impacts and crew health requirements and a database of regolith simulants used for ground testing and a NASA standard for ground testing methods. The Artemis program uses these data sources to develop requirements, mitigation methods, and design validation.

NASA's dust mitigation strategy promotes the identification of new technology, aligns the concept of operations approach across all mission entities, promotes efforts to increase modeling capabilities, and emphasizes the use of lessons learned and flight data. Artemis mission planning reflects our expectation to continually learn from Artemis Missions' flight observations and gathering of dust behavior data and mitigation efficacy as we advance capability on the lunar surface.

Overview of approach:

1. Develop knowledge base and technology for lunar dust management and mitigation

2. Collect, compile, and analyze lunar dust data, including results from Commercial Lunar Payload Services Missions

3. Develop and maintain a Dust Mitigation Concept of Operations to frame dust mitigation strategy

4. Validate Program requirements, assumptions, and design implementations against lunar dust data sources

5. Ensure programs implement a combination of:
   a. Design techniques to limit the collection and transport of lunar dust,
   b. Removal techniques to remove lunar dust from equipment,
   c. Mitigation techniques to eliminate, reduce, or contain the spread of lunar dust, and
   d. Crew provisions for maintaining crew health in the presence of lunar dust

5. Verify operational plans and procedures are consistent with the design, removal, and mitigation techniques established within each program

7. Infuse passive and/or active dust mitigation technology

8. Apply Lessons Learned and collect data from Artemis missions to improve the knowledge base, design, models, simulations, and future mitigation steps

Examples of focus areas that NASA and its partners are considering to mitigate the effects of lunar dust include modeling and testing the interaction of rocket plumes and lunar surface dust, ensuring that lunar system designs protect airlock and docking hatches and flight-critical mechanisms with adequate covers or seals, ensuring that life support systems are equipped with adequate air filtration to remove airborne dust, and allocating sufficient crew time during the mission for inspection and cleaning of critical devices and surfaces.

4. **In accordance with NASA Space Flight Program and Project Management requirements, NASA must establish baseline cost commitments for the Space Launch System (SLS) and the Exploration Ground Systems (EGS). While the agency has done so for Artemis I, that mission has now taken place. However, NASA has not yet established baseline cost commitments for SLS and EGS for subsequent Artemis missions, such as Artemis II and Artemis III, or for additional Artemis capabilities, such as the SLS Block1B or the Mobile Launcher – 2 platform. When can the Committee and Congress expect to get such information which is needed to understand the investments that NASA is making, and that the Congress must oversee, for Artemis and the Moon to Mars program?**

   Response: The HLS Initial Capability was approved with a baseline development cost of $2,339 million and a baseline schedule milestone of Lunar Orbit Checkout Review (LOCR) in February 2028 at a joint confidence level of 70 percent. The agency's Artemis III launch planning date is September 2026; detailed program schedule-level updates for Artemis III dates are in work.

Gateway Initial Capability was approved with a baseline development cost of $3,562 million and a baseline schedule milestone of Launch Readiness Date (LRD) in December 2027 at a joint confidence level of 70 percent.

The SLS-Block-1B was approved with a baseline development cost of $3,675 million and a baseline schedule milestone of Design Certification Review (DCR) in January 2028 at a joint confidence level of 70 percent. The agency's Artemis IV launch planning date is September 2028; detailed program schedule-level updates for Artemis IV dates are in work.

The ML2 ABC was confirmed in April 2024. The ML2 capability will support Artemis IV and subsequent launches.

Questions submitted by Full Committee Ranking Member Zoe Lofgren

1. **The SpaceX approach for its human landing system, which will be used for the first human landing on the Moon in over 50 years, requires an estimated 10 or more launches to deliver cryogenic propellant to an on-orbit fuel depot. The plan involves storing the propellant in the fuel depot and managing the effects of "boil off" until a Starship human landing system is launched and proceeds to rendezvous and dock with the depot for transfer of the propellant to the Starship human landing system before it journeys to cislunar space for docking with the crewed Orion vehicle in advance of a human landing on the lunar surface.**

    a. **What is the technology readiness level of the on-orbit propellant storage and transfer technology needed for the initial Artemis III human landing system?**

    Response: NASA assesses the HLS propellant storage and transfer technology needed for Artemis III is at a technology readiness level of 4/5.

    b. **Please name the tests and demonstrations, and the estimated dates, that SpaceX will carry out over 2024-2025 to advance this technology.**

    Response: In accordance with a NASA Space Technology Mission Directorate Tipping Point contract with SpaceX, a tank-to-tank propellant transfer demonstration within a single Starship vehicle was conducted during the March 2024 launch of Flight Test 3.

    The NASA HLS contract with SpaceX includes a Propellant Storage and Transfer Architecture review by the spring of 2025. This review will be informed by the in-space demonstration of Starship-to-Starship propellant transfer and long duration cryogenic propellant storage capabilities, which could be implemented during separate flight tests or during a single integrated flight test. The HLS SpaceX contract also includes an Uncrewed Lunar Landing Flight Test to be conducted by the Fall of 2025. This test will further demonstrate and mature propellant storage and transfer technology.

2. **Will NASA have access to the data from the SpaceX tests and demonstrations on cryogenic fluid management, as well as the Space Technology Mission Directorate Tipping Point cryogenic fluid management demonstrations NASA has funded, in order to validate NASA's own models on cryogenic fluid management, inform its understanding of the design and performance of the SpaceX cryogenic fluid management and transfer technologies, and advance the broader industry?**

Response: The NASA Space Technology Mission Directorate's Tipping Point contract requires SpaceX to deliver to NASA all identified flight data supporting cryogenic fluid management (CFM) technology development. NASA, using its CFM Subject Matter Experts, identified the most CFM-relevant aspects of the Orbital Flight Test (OFT3), and included that data as deliverable under Tipping Point contract. Additionally, CFM data will be delivered to NASA for other Starship flights conducted between OFT3 and the contract end date in November 2024. The cryogenic propellant transfer, the primary focus of the Tipping Point contract, will not be performed on those flights. NASA will leverage this data to validate models for propellant storage,

boil-off, and transfer operations. NASA will disseminate all unlimited marked flight data and model validation effort results direct to the broader industry starting after the Fall 2024 timeframe.

3. **The 2022 NASA Authorization Act, enacted as part of the CHIPS and Science Act, required the establishment of a Moon to Mars program office and designation of a Moon to Mars Program Director. How has the new office affected the way NASA manages and integrates programs that support Artemis missions?**

   Response: The new Moon to Mars (M2M) Program Office was established in March 2023, effectively combining the three programs of the Common Exploration Systems Development division with the three programs of the Artemis Campaign Development division. These divisions previously implemented a capabilities development approach, wherein missions were derived and planned to align with the availability of developed hardware. In the new construct, which is objectives and mission driven, the Program Office is responsible for the establishment of strategy and objectives for each Artemis mission, integrated management of mission baselines, the management of cross-program control milestones, and integrated systems engineering processes managed across mission (rather than program) phases. The integration of these divisions by the Program Office has led to the establishment of new, streamlined governance processes, including the establishment of both technical and programmatic decisional boards with all six programs.

   a. **What risks does the use of differing and asynchronous contracting approaches for key Artemis elements pose, and how is the authority of the Moon to Mars Program Director being exercised to address such risks?**

      Response: The diversity of contracting approaches employed in the Moon to Mars program reflect the many different stages of hardware development currently represented across Artemis missions and does not, by itself, pose any risks to the missions or program management. Quite the opposite, the use of a variety of incentives and awards, the flexibility to allocate risk depending on developmental phase, and the tailoring of oversight/insight allows NASA to facilitate competition in the deep space industry.

      Nonetheless, the management of an integrated mission baseline does necessitate alignment between contracts to reduce the impacts of schedule issues and cost growth on the overall mission baseline. The Moon to Mars Program Office addresses risks by identifying shared means of mitigating supply chain issues common to multiple primes, ensuring primes maximize workforce efficiencies between primes through cross-training, and facilitating exchange of lessons learned.

4. **What is NASA's contingency plan for its Artemis III human landing mission should the existing technical approach or integral key systems fail or take years longer than the current plan?**

   Response: With two competing landers presently being developed by commercial partners, NASA has mitigated the risk of having no lander available for an Artemis III lunar landing. More importantly, however, the Artemis missions constitute a long-term exploration campaign meant to enable sustainable human exploration of deep space. Therefore, if there are delays, Artemis hardware has been developed to flexibly pursue other test objectives

and/or science goals in cis-lunar orbit. Each flight of its foundational systems – whether landing on the surface or remaining exclusively orbital – will be used to reduce risk to crew safety, perform groundbreaking science, and deliver elements or payloads to enable a sustainable lunar orbit presence via Gateway.

a. How is NASA thinking about resiliency in Moon to Mars plans and architectures?

Response: The Moon to Mars plans and architectures are resilient in several different ways. First, the development and yearly re-examination of architecture objectives through systematic Architecture Concept Reviews establish an upfront blueprint for long-term goals. By incorporating international and commercial inputs into the planning process, areas for collaboration and growth are identified early. In this manner, Artemis architecture is being developed for a future in which commercial and international users provide complementary contributions in lunar research and development and in preparation for future flights to Mars. Efficiencies are gained, and redundancies are reduced.

Artemis hardware – launch systems, crew vehicles, Gateway, landers, and so forth – is developed and managed to support both lunar orbit and lunar surface objectives. As missions develop over time, concepts of operations may evolve to maximize utilization. Regardless, each element affords the flexibility to pursue different risk-reducing objectives concurrently.

Finally, NASA's investment reflects a commitment not only to build exploration hardware, but also to enable access to deep space and stimulate the appetite of a burgeoning American space economy. In that context, NASA is building resiliency through the restarting of production lines, stimulating industry competition and innovation, and training American workforce on development, testing, and qualification of highly specialized space systems.

Questions submitted by Rep. Mike Garcia

1. **During the hearing you discussed how important NASA's workforce is and how difficult it is for the Administration to find qualified candidates. Earlier this month, NASA ordered the laying-off of 100 contractors attached to the Mars Sample Return (MSR) Mission and ordered a stoppage of all work related to the Mission by the end of January. In a letter to employees, NASA warned that further layoffs will likely be necessary.**

    a. **Is the MSR Mission the "highest scientific priority of NASA's robotic exploration efforts" as recommended in the most recent decadal survey?**

Response: MSR was the highest priority planetary science mission recommended in the National Academies' Decadal Survey for Planetary Science and Astrobiology. The decadal survey also recommended that all elements of the MSR campaign (including the Sampling Receiving Project) should not exceed 35 percent of the Planetary Science Division (PSD) annual budget, that NASA continue to maintain a balanced portfolio of small, medium, and large missions, and that NASA continue investments in Research and Analysis and Technology Development.

    b. **What is NASA doing to minimize the loss of skilled workers by these cutbacks — which have not been approved by Congress?**

Response: The management of contractor workforce at NASA's FFRDC, the Jet Propulsion Laboratory (JPL), is directed by JPL. NASA provides programmatic direction, along with budgetary resources, and relies on JPL to determine the workforce and skill mix necessary to accomplish the work within the budget allocated. NASA does not direct JPL to maintain certain levels of workforce, nor does NASA get involved in JPL personnel matters. JPL plays a key role in the success of many NASA Science missions. NASA is committed to ensuring workforce levels for JPL are commensurate with known mission requirements and available resources.

The enacted FY24 appropriation for Planetary is nearly $0.5B below FY23 enacted and $0.7B below the FY24 request, reducing NASA's ability to fund many missions and activities near the requested level. In FY 2024, NASA plans to fund MSR at $310.0 million, which will support an internal review of the IRB-2 findings and alternative architecture studies, completion of CCRS close-out activities (at GSFC and JPL) necessary to position the project to potentially be resumed in the future, work on aspects of the mission that have a high likelihood of being used in any future architecture, and industry and NASA Center studies to solicit innovative options for a future mission architecture.

2. **If NASA chooses to cut Mars Sample Return funding to $300 million annually—nearly 1/3 of Congressionally appropriated levels—are you confident that the United States can beat China in the race to return a sample from Mars? How would any significant delay in the Mars Sample Return Mission affect the United States' goal of being the first nation to set foot on Mars?**

Response: NASA does not have any plan to fund Mars Sample Return at $300 million annually and thus cannot predict when such a plan would result in the return of a sample from Mars. While returning a sample from Mars will provide valuable information that will better prepare us for

human exploration of Mars, MSR is not part of the Artemis architecture for returning astronauts to the Moon or to put astronauts on Mars.

3. **As discussed during the hearing, NASA discovered more erosion to Orion's heat shield than expected, leading to the delay of Artemis II. Can you provide an update on the state of NASA's root cause analysis? Is NASA studying any alternative heat shield materials? Can you tell me whether those efforts will inform Artemis return-to-flight plan or future flights of Artemis?**

   Response: The Artemis I Heat Shield Char Loss investigation has a dedicated team conducting testing, performing detailed analysis, and gathering data from samples of the heat shield. The team has nearly completed an extensive set of ground-based aerothermal and aerodynamic testing to recreate the phenomenon that will help determine root cause. Upon completion of recreating the phenomenon and identifying the root cause, the data will help inform the path forward for Artemis II and future flights.

Questions submitted by Rep. Darrell Issa

1. **During the hearing, you spoke about reducing mortality and increasing safety in space. Would you please provide responses to the following:**

   a. **How many astronaut deaths have occurred as a result of space travel?**

   Response: Fifteen NASA astronauts have died during a mission.

   - Michael J. Adams, X-15 Flight 3-65-97 (astronaut wings awarded posthumously after mission exceeded altitude of 50 miles before accident), 1967
   - *STS-51-L Challenger* crew: Gregory Jarvis, Christa McAuliffe, Ronald McNair, Ellison Onizuka, Judith Resnik, Dick Scobee, Michael J. Smith, 1985
   - *STS-107 Columbia* crew: Michael P. Anderson, David M. Brown, Kalpana Chawla, Laurel Clark, Rick D. Husband, William C. McCool, Ilan Ramon, 2003

   Four Soviet cosmonauts have also died during a mission.

   - *Soyuz 1* crew: Vladimir Komarov, 1967
   - *Soyuz 11* crew: Georgy Dobrovolsky, Viktor Patsayev, Vladislav Volkov, 1971

   b. **How many astronaut deaths have been caused by training and preparation for a space mission?**

   Response: Eight NASA astronauts and astronauts-in-training have died during mission training.
   - Theodore Freeman, jet training accident, 1964
   - Elliot See and Charles Bassett, jet training accident, 1966
   - *Apollo 1* crew: Virgil "Gus" Grissom, Ed White, Roger B. Chaffee, 1967
   - Clifton C. Williams, jet training accident, 1967
   - Robert Henry Lawrence Jr, jet training accident, 1967

   Another American, Michael Alsbury (2014), died during a test of the private spaceship *VSS Enterprise*.

   One Soviet cosmonaut trainee, Valentin Bondarenko (1961), and one Russian cosmonaut trainee, Sergei Vozovikov (1993), were also acknowledged as having died during training.

   c. **How many deaths have been reported while traveling on a mission to the Moon?**

   Response: No astronauts have died while traveling on a mission to the Moon, although the crew of *Apollo 13* had to abort their planned lunar landing following an explosion of an oxygen tank on the service module.

   d. **How many deaths have been reported while returning from a mission on the Moon?**

   Response: No astronauts have died while traveling on a mission to the Moon.

Questions submitted by Rep. Dale Strong

1. **Now that NASA has successfully demonstrated SLS capabilities, what are the use cases for SLS that NASA is investigating beyond the Artemis campaign?**

    a. **When is the Agency planning to submit requests for funding to support the full use of the vehicle in both crew and cargo variations in order to achieve a sustained U.S. presence on the Moon?**

    Response: NASA successfully demonstrated the SLS Block 1 uncrewed capability in November 2022 and plans to launch the SLS Block 1 crewed capability by September 2025. The Agency's baseline plan is to fly the SLS in a crewed configuration to support the Artemis missions, with one-a-year crewed flight on a SLS Block IB vehicle after Artemis IV. This plan maximizes the utilization of the SLS in its most important role: protecting the crew as they travel to deep space and then safely back. The plan also includes, on Artemis IV and beyond, using the SLS Block IB crewed configuration with the ability to deliver a 10 mT co-manifested payload, the size of a medium ISS module, for each mission. With the Artemis IX mission, NASA will debut the SLS Block 2 capability providing performance of 130 t for payload to Low Earth Orbit and greater than 43 t for Trans Lunar Injection (TLI) for deep-space exploration. This capability will primarily upgrade the current Solid Rocket Boosters with composite casing under the effort entitled Booster Obsolescence and Life Extension.

    An SLS Block IB cargo variant is not in the current Artemis baseline plan for use of the SLS launch system.

2. **How does NASA anticipate the role of the SLS evolving in response to the dynamic space ecosystem, particularly considering the rapid advancements in space technology by countries like China and emerging private space companies?**

    Response: SLS's role has already evolved since its initial announcement. In addition to its key mission of delivering Orion and its crew safely to lunar orbit SLS will help the building of the internationally partnered Gateway and in carrying some lunar surface payloads to lunar orbit..

    Additionally, the diversity of Artemis providers involved in developing American exploration plans allow these systems to expand American possibilities in deep space far beyond those of China's monolithic program. The Chinese Long March 10 rockets will have ~27-ton capability to TLI, which is roughly similar to the initial SLS Block 1 configuration. By comparison, the evolved SLS Block 1B vehicle will have the ability to carry ~40 tons of payload to TLI, and the Starship Human Landing System will have the ability to land ~100 tons on the lunar surface. The Blue Moon landers will provide additional sustaining landing capabilities as well. The SLS and partnered human landing services will respond to Chinese plans with flexibility that can only be afforded by a competitive market.

Questions submitted by Rep. Rich McCormick

1. **In November the Biden Administration released their White House Mission Authorization Proposal. In the weeks following the commercial space industry has expressed several concerns including potential for "duplicative and conflicting" requirements between the Department of Commerce and the Department of Transportation and that increased regulation will stifle the commercial space industry that NASA so heavily relies on. Are there any concerns that if this legislative framework were to be implemented that the lack of a 'one stop shop' for licensing and permitting would lead to further delays for the Artemis mission considering its heavy reliance on the commercial space industry?**

   Response: NASA has intentionally developed commercial space capabilities with the goal of increasingly serving as a customer of these commercial services in order to meet agency goals. Therefore, as NASA acquires more and more of these commercial services, including for the Artemis program, the success of NASA becomes inextricably linked to the success of the industry. NASA believes the best way to guarantee success for everyone is to establish a clear, predictable, and logical mission authorization to guide industry, as well as protect NASA missions from potential interference by commercial missions. As it relates to Artemis, NASA will continue working with the Federal Aviation Administration (FAA) and industry to ensure that all necessary safety and public interests are adhered to while maintaining steady progress to landing astronauts on the Moon. NASA and FAA have discussed the required number of flights and flight rate to execute each Artemis mission. Consequently, NASA does not believe implementing the National Space Council's mission authorization proposal would delay Artemis missions. NASA notes that a one stop shop does not exist today; rather this National Space Council proposal is an extension of existing statutory authorities to regulate commercial space activities at both DOT/FAA and the Department of Commerce. Further, under the National Space Council proposal, multiple new licenses for novel commercial activities are not needed. Any novel space activities that are part of a mission would require either a FAA or Department of Commerce license, but not both.

Responses by Mr. William Russell

U.S. GOVERNMENT ACCOUNTABILITY OFFICE

441 G St. N.W.
Washington, DC 20548

February 22, 2024

The Honorable Brian Babin
Chair
Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology
U.S. House of Representatives

Subject: *Responses to Questions for the Record regarding the hearing entitled "Returning to the Moon: Keeping Artemis on Track"*

Dear Representative Babin,

Thank you for the opportunity to appear before the Committee on Science, Space, and Technology Subcommittee on Space and Aeronautics on January 17, 2024 to discuss NASA's efforts to return astronauts to the surface of the Moon and ultimately human exploration of Mars through its Artemis missions. This letter responds to your February 8, 2024 request that I provide an answer to questions for the record from the hearing. The questions, along with my responses, are enclosed. Responses are primarily based on work done for the testimony's related report and prior work.

Sincerely yours,

W. William Russell
Director
Contracting and National Security Acquisitions

Enclosure: Responses to Member Questions

cc: The Honorable Eric Sorenson
Ranking Member
Subcommittee on Space and Aeronautics

Response to Post-Hearing Questions for the Record
"Returning to the Moon: Keeping Artemis on Track"
Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology
U.S. House of Representatives
Hearing held on January 17, 2024
Questions for W. William Russell, Director, Contracting and National Security Acquisitions
U.S. Government Accountability Office

Questions submitted by Chairman Brian Babin

1. **During the hearing you identified the 1-year gap between Artemis 2 and Artemis 3 as a schedule pressure for the program, particularly given the time needed to make changes to Artemis 3 based on the lessons learned during the Artemis 2 mission. What do you think is a reasonable estimate of the gap needed between Artemis 2 and Artemis 3? Additionally, since Artemis 3 is contingent on the results of the Artemis 2 mission, what contingency planning should NASA do in anticipation of the need for corrective actions identified during the Artemis 2 mission?**

Artemis I successfully concluded in December 2022. Since that time, NASA has reviewed data from the test flight and is incorporating lessons learned into Artemis II hardware and planning.

Artemis II will rely on the same three systems from Artemis I – Space Launch Systems Block 1, the Orion Multi-Purpose Crew Vehicle, and the Exploration Ground Systems. NASA has determined that it will need almost three years from the Artemis I mission before it believes it will be ready to safely fly Artemis II in September 2025.

Artemis III adds another two systems into the mission profile – Human Landing System – Initial Capability and space suits – bringing the total number of programs to five. There will be schedule pressure for NASA to respond to any new information gathered during the Artemis II mission and incorporate it into the hardware or mission operations while simultaneously integrating five programs to conduct the first human lunar landing since 1972.

2. **GAO has conducted numerous studies specifically on the Artemis program, as well as more broadly on NASA's acquisitions and program execution, planning, and management. Across these studies, GAO has made many recommendations for NASA that are relevant to the Artemis program. What do you see as particularly important recommendations that NASA has not yet implemented?**

NASA's acquisition management is one of the highest risks facing the agency due to the history of cost growth and schedule delays of its major projects. As of May 2023, GAO has identified six priority recommendations related to NASA's management of Artemis programs or missions. [1]

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[1]GAO, *Priority Open Recommendations: National Aeronautics and Space Administration*, GAO-23-106496 (Washington, D.C.: May 3, 2023) Priority recommendations are those that we believe warrant priority attention from heads of key departments or agencies. They are highlighted because, upon implementation, they may significantly

These recommendations are primarily focused on improving transparency into long-term costs and affordability of human spaceflight programs. For example, NASA should identify a range of possible missions for each future Space Launch System variant that includes cost and schedule estimates and plans for how those possible missions would fit within NASA's funding profile. In addition, NASA has yet to create a life-cycle cost estimate for the Artemis III mission, which is important as NASA plans for this mission to return U.S. astronauts to the surface of the moon in 2026. Implementing these priority recommendations is critical for NASA to provide assurance that it will sustain the progress it has made toward addressing key acquisition management issues on its largest and most complex missions.

Questions submitted by Ranking Member Eric Sorensen

1. **In responding to one of my questions during the hearing, Ms. Koerner said, "I will also note to the comment about the cost and cost transparency, one of the challenges that we face in answering a per-mission cost is our contracts are set up to do bulk buys. In other words, we get--if I go buy three of something, I can get it less expensive than if I buy one of something three times. So when we have--establish our contracts and we purchase some of our equipment, those bulk buys give us cost savings. But what those do is it lumps costs together in by program and by purchases…. we don't, for example, get appropriations for Artemis missions." What are your perspectives on NASA's rationale for not establishing costs for each Artemis mission?**

    a. **In your view, does NASA have the information it needs to establish a baseline commitment for an Artemis mission?**

In our December 2019 report on NASA's lunar programs, we recommended that the agency create a life-cycle cost estimate for the Artemis III mission.[2] NASA agreed with the recommendation. However, NASA has not yet created this cost estimate. In February 2023, NASA officials told us that they were developing a methodology to provide Congress with an assessment of each Artemis mission's costs. NASA officials stated that the mission estimates will include the cost of hardware production, integration costs, and operations costs, but did not provide a time frame for when this would be completed.

We continue to believe that NASA should develop a life-cycle cost estimate for the Artemis III mission and that the agency has the information it needs to do so. To fully implement this recommendation, NASA needs to develop a life-cycle cost estimate for the lunar landing mission as a whole. NASA will need to find a way to exclude costs outside of this mission, such as costs for the Artemis I and II missions, from budget estimates or contracts. For example, for some of the programs in the mission, like the Space Launch System, the agency does not have a baseline cost to use because it did not include the scope of work required for the Artemis III mission in its cost baseline. The program's baseline included a cost estimate only for the

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improve government operations, for example, by realizing large dollar savings; eliminating mismanagement, fraud, and abuse; or making progress toward addressing a high-risk or duplication issue.

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

Artemis I mission. NASA previously stated that the agency planned to use contracts to determine the cost to produce and operate hardware in the mission that has been previously has been produced and operated in prior missions. For other programs, such as the Human Landing System initial capability, NASA will be able to use the program's baseline costs in its estimate because the scope of the baseline is the Artemis III mission.

Questions submitted by Full Committee Ranking Member Zoe Lofgren

1. **In response to direction in the 2022 NASA Authorization Act included in the CHIPS and Science Act [P.L. 117-167], NASA recently established the Moon to Mars Program Office at NASA to carry out the agency's human exploration activities, including Artemis. To what extent is the Moon to Mars Program Office addressing previous concerns GAO has raised regarding organization, accountability, and risk management in NASA's lunar programs?**

    a. **What additional steps, if any, can the Moon to Mars Program Office take to address such concerns?**

In November 2023, we found that the Moon to Mars program office is leveraging previous work performed by the Artemis Campaign Development Division on integrating across the programs to support the Artemis missions.[3] For example, NASA's Moon to Mars Program Office is addressing performance and safety risks related to the known harm that lunar dust could inflict on the hardware and crew. It is addressing these risks across the Human Landing System, space suits, and Orion programs based on lessons learned from the Apollo mission and subsequent research. Additionally, in January 2024, the Aerospace Safety Advisory Panel found that the Moon to Mars program office had positioned all the integrated risk management responsibility under a single hierarchy, established traditional program management risk processes, and conducted an agency-wide architecture review process, which will be key to NASA's success in returning to the moon and beyond.[4]

We have made several recommendations to the NASA administrator that, if fully implemented, could significantly improve agency operations.[5] All six of GAO's priority recommendations related to monitoring program costs and execution are related to NASA's management of Artemis programs or missions. For example, we recommended that NASA establish cost and schedule baselines for the Space Launch System (SLS) Block 1B, SLS Block 2, Mobile Launcher 2, and Orion Docking System at their preliminary design review. NASA agreed with this recommendation. In December 2023, NASA established a cost and schedule baseline for SLS Block 1B, and NASA plans to set a baseline for Mobile Launcher 2 in spring 2024. Establishing baselines for these programs will provide the Moon to Mars program and other decision makers an important oversight tool to monitor program performance.

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[3]GAO, *NASA Artemis Programs: Crewed Moon Landing Faces Multiple Challenges*, GAO-24-106256 (Washington, D.C.: Nov. 30, 2023).

[4]Aerospace Safety Advisory Panel, *Annual Report,* (Washington, D.C.: Jan 1, 2024).

[5]GAO-23-106496.

Questions submitted by Rep. Mike Garcia

1. **If NASA chooses to cut Mars Sample Return funding to $300 million annually—nearly 1/3 of Congressionally appropriated levels—are you confident that the United States can beat China in the race to return a sample from Mars? How would any significant delay in the Mars Sample Return Mission affect the United States' goal of being the first nation to set foot on Mars?**

In September 2023, a second independent review board assessed the Mars Sample Return program and found a) the strategic and scientific value of the program was not communicated appropriately; b) the program was established with unrealistic budget and schedule expectations; and c) there was not a credible cost, schedule, or technical baseline that can be accomplished with likely available funding. To demonstrate sustained improvement in cost and schedule performance for its portfolio of major projects, NASA will need to control the extent to which the most expensive and complex category 1 projects have cost overruns and schedule delays, including Mars Sample Return.

NASA's 2020 Science Mission Directorate Large Mission Study collected lessons learned following cost and schedule overruns in some of NASA's flagship missions, including the James Webb Space Telescope. It included findings and recommendations aimed at the creation, execution, and oversight of large strategic missions. The agency started implementing some of these recommendations for Mars Sample Return.

Questions submitted by Rep. Darrell Issa

1. **Because NASA has previously sent missions to the Moon – with much less sophisticated technology and knowledge – I am perplexed by the setbacks we are experiencing. Can time delays and cost overruns be attributed to an attempt to over-complicate a known process with new technology?**

We have found that historically NASA has faced challenges with cost and schedule performance on its most expensive projects, which include projects supporting the Artemis missions. We previously reported on key cost drivers for the Artemis-related major projects, which include schedule delays as well as manufacturing challenges for the Space Launch System, and contractor performance issues for the Orion Multi-Purpose Crew Vehicle. In May 2023, we found that twelve of NASA's 16 major projects in development have experienced schedule delays.[6] According to NASA officials, technical issues are the driving factor as to why most major projects experienced cost or schedule growth.

The goal of NASA's Artemis enterprise is to return U.S. astronauts to the surface of the moon, establish a sustained lunar presence, and, ultimately, achieve human exploration of Mars. The projects supporting the Artemis missions are complex and specialized, and often push the state of the art in space technology. These projects are planned to allow NASA to return to the lunar surface for the first time since the Apollo missions. Unlike the Apollo missions, once NASA

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

returns to the moon, the Artemis projects are intended to help NASA to build a long-term presence on the moon and eventually grow the lunar economy.

Responses by Mr. George A. Scott

Questions submitted by Chairman Brian Babin

1. In 2019, as a priority recommendation, GAO urged NASA to develop a life-cycle cost estimate for Artemis 3, in order to provide Congress with insight into the mission's affordability. The GAO website still lists this recommendation as open. NASA initially stated that it would establish cost and schedule commitments for projects, but not the Artemis 3 mission overall. In February 2023, NASA indicated that it would develop a methodology to provide Congress with an assessment of each Artemis mission's costs, but it did not provide a time frame for this. What is the status of the development of a process for creating life-cycle cost estimates for individual Artemis missions and when do you expect it will be completed?

RESPONSE: Similar to GAO, in a November 2021 report (IG-22-003) we recommended that NASA's Associate Administrator for Exploration Systems Development (ESD) Mission Directorate maintain an accounting of per-mission costs to increase transparency and establish a benchmark against which NASA can assess the outcome of initiatives to increase the affordability of ESD systems. According to Agency officials, at that time NASA was developing a methodology to provide Congress with a repeatable assessment of mission costs for each mission in its Artemis campaign. This action was due in February 2023, but has yet to be completed. We made a similar recommendation in an April 2022 report (IG-22-011) to which the Agency agreed to develop a methodology; however, they recently approached our office about their intention not to follow through on that commitment.

2. NASA OIG previously reported that one Space Launch System launch would cost the government $2 billion and that NASA's efforts to reduce this cost were unlikely to significantly lower it. Can you talk about what drives the Space Launch System costs and steps that NASA can or has taken to lower them?

RESPONSE: A number of interrelated factors contribute to the high cost of ESD programs. First, in the NASA Authorization Act of 2010, Congress directed NASA to incorporate preexisting Constellation-era contracts and modify heritage equipment from the Space Shuttle and Constellation Programs in developing the Space Launch System (SLS) and Orion Multi-Purpose Crew Vehicle (Orion). As such, these large development contracts—the SLS's stages, boosters, and engines, and Orion's capsule—were sole sourced, eliminating any potential cost benefits of competition. Competing follow-on awards for production several years later became a non-starter due to the high cost of a new contractor instituting its own manufacturing processes and building facilities—a cost estimated at $4.5 billion for the Core and Exploration Upper Stages. Second, NASA continues to use a cost-plus contracting structure. Third, multiple contractors associated with the SLS have been permitted to begin work without NASA adequately defining the contract's specific terms. For example, the first stages contract took 2 years before NASA and the contractor agreed on pricing and NASA is still negotiating the follow-on production contracts for the SLS boosters and stages. Over time, failure to agree on such key contract terms reduces the government's ability to influence the final pricing as it invests more time and money into a project. Finally, NASA has not consistently used the award fee structure to incentivize better contractor performance. Even when a contractor performed poorly, NASA provided award fees commensurate with a company whose performance was very good or excellent. For example, despite being 3 years behind schedule and billions over budget, The Boeing Company averaged 86 percent in award fees for core stage production over the life of the initial SLS Stages contract, receiving a "very good" rating. In another case we reported on in May 2023 (IG-23-015), after a contracting officer for the SLS booster office denied Northrop Grumman's request multiple times over a 4-year period for award fees on costly redesign work, the SLS Program ultimately conceded and recommended an "excellent" award fee rating for work previously considered unsatisfactory.

To its credit, NASA has acknowledged the high costs of the SLS and has been exploring ways to make it more affordable. Perhaps the Agency's most ambitious affordability effort is the future award of a sole-sourced services contract, known as the Exploration Production and Operations Contract (EPOC), to Deep Space Transport, LLC—a newly formed joint venture of The Boeing Company and Northrop Grumman Systems Corporation—for the production, systems integration, and launch of at least five and up to ten SLS flights beginning with Artemis V scheduled for 2029. Through EPOC, NASA hopes to reduce the $2.5 billion cost of a single SLS rocket by 50 percent through workforce reductions, manufacturing and contracting efficiencies, and expanding the SLS's user base.

However, as we reported in October 2023 (IG-24-001), this goal realistically cannot be achieved and the production cost alone will remain over $2 billion.

Despite these challenges, NASA can take steps to improve EPOC's cost savings potential. In the near term, NASA must stabilize technologies and requirements to maximize the use of fixed-price contracts. The continued use of SLS cost-reimbursable contracts by EPOC will likely stymie any significant cost saving efforts. In addition, several FAR provisions may assist NASA in contract negotiations and mitigate the impact of schedule and cost overruns. Finally, in the long term, commercial competition in launch services will be more practicable for the Agency to better leverage less costly commercial alternatives while achieving its mission goals. Several U.S. space flight companies are already implementing multiple technological innovations, making heavy-lift systems lighter, cheaper, and reusable. In the end, failure to significantly reduce the SLS launch vehicle's high costs will significantly hinder the overall sustainability of the Artemis campaign and NASA's deep space human exploration efforts.

3. Does the Moon to Mars program abide by the same requirements as other NASA acquisition programs including requirements for systems engineering and to set cost and schedule baselines? If not, why, and what requirements does the program have to abide by?

RESPONSE: We recommend referring this question to the appropriate NASA officials, who would be better positioned to address questions regarding the requirements for systems engineering and cost and schedule reporting that the Moon to Mars Program must follow. That said, it is important to note that the Moon to Mars Program itself is not a program as defined by NASA Procedural Requirement 7120.5F, meaning it does not abide by the same requirements as traditional NASA acquisitions which require cost and schedule baselines. Instead, the Moon to Mars Program Office brings various Artemis-related programs under central leadership, focusing on hardware development, mission integration, and risk management functions critical to the Agency's deep space exploration goals.

Questions submitted by Ranking Member Eric Sorensen

1. In several of the NASA Office of Inspector General's (IG) reports on projects supporting Artemis missions, your office questioned award-fee payments that NASA made to contractors who were not meeting cost and schedule expectations. Has NASA implemented any of the IG's recommendations? Are you still finding questionable award fees?

RESPONSE: In general, the Agency has made some progress in implementing the Office of Inspector General's recommendations related to award fees. Since initially questioning award fee payments under the Mobile Launcher 1 ($64 million, IG-20-013) and Orion ($27.8 million, IG-20-018) contracts that experienced cost and schedule challenges, we found similar questionable award fees in our June 2022 Mobile Launcher 2 (IG-22-012) and May 2023 SLS booster and engine contracts (IG-23-015) audits. Under the Mobile Laucher 2 audit, we questioned $3 million in award fees. In August 2023 in response to a recommendation on this matter, the Agency took action to ensure acquisition officials would minimize the availability of award fees when contract modifications and value increases are the result of shortcomings in contractor performance and require documentation of the rationale for any award fees granted. To its credit, the Agency also did not provide any award fees to Bechtel for the October 2021 to March 2022 award fee period due to the contractor's poor performance. However, in our SLS booster and engine contracts report we questioned over $44 million in settled award fee payments for work that resulted in increased cost and schedule on the SLS boosters contract and for work that was never completed under the SLS RS-25 engine adaptation contract for 11 of 14 engines. The Agency estimated taking closure actions for these two award-fee specific recommendations in June and September 2023 but has yet to do so.

2. The NASA IG released a report in October 2023 assessing NASA's management of the Artemis supply chain. That report found that other government agencies and private industry use more proactive supply chain monitoring and management practices than NASA. What are other government agencies doing and how can NASA be more proactive in supply chain monitoring and management for the Artemis effort?

RESPONSE: In our October 2023 report (IG-24-003), we identified a variety of supply chain management best practices and benchmarking opportunities from other federal agencies, an international partner, and private sector companies. Specifically, we found that the U.S. Departments of the Navy, Army, and Air Force, as well as the Defense Contract Management Agency (DCMA), are each, to varying degrees, refining their insight into their supply chains. In addition, the European Space Agency (ESA)—one of NASA's main international partners for the Artemis campaign—illustrates how NASA can improve its management of unique supply chains. Further, we researched best practices from private sector companies outside of the space flight sector—the automobile industry, in particular—that face similar supply chain difficulties to NASA.

Department of the Navy. In 2014, the Department of the Navy began developing a supply chain database that allows it to identify its most critical suppliers based on several factors, including parts with long lead times, high dollar values, and those from single or sole sources. In recent years, the Navy began implementing Contract Data Requirement Lists—a required data submission from the contractor similar to NASA's Data Requirement Deliverables—into contracts to require shipbuilders to continue to provide this information. Codifying these requirements into major contracts allows the Navy to receive vast quantities of data it can use to maintain visibility into its supply chains. NASA is currently developing the Supply Chain Visibility Data Requirement Deliverable to provide the Agency with similar supply chain information from its prime contractors.

Department of the Army. One office we spoke to within the Department of the Army gains extensive insight into its supply chains by utilizing an existing contract vehicle with a third-party service. While the service is costly, the capabilities are robust, and Army officials told us it is extremely useful. Dashboards are populated with supplier data from bills of material from several Army programs and supplemented with opensource data and reports created using artificial intelligence. These dashboards, as well as specialized reports, provide more transparency and traceability of the Army's critical suppliers compared to NASA.

Department of the Air Force. The Department of the Air Force is collaborating with NASA's Aeronautics Research Institute to lead a supply chain working group for NASA's Advanced Air Mobility mission. While the group is mostly an educational forum given the nascency of the drone market its members are studying, the working group actively engages with industry to establish relationships and discuss ideas. According to working group leadership, suppliers embraced the opportunity to meet with the Air Force and NASA to engage on these issues. In comparison, NASA's Supply Chain Resiliency Forum does not have representation from each Agency Mission Directorate or any program-level personnel, let alone anyone from industry. Based on the amount of insight gleaned from our discussions with Artemis prime contractors, a fuller and more holistic membership for the this forum would provide additional perspectives on important supply chain issues.

Defense Contract Management Agency. DCMA is taking several actions to improve its supply chain management. The agency is transitioning from two separate internal databases to the Navy's PDREP database to oversee its supply chain management and increase the fidelity of data on its suppliers. Additionally, as a best practice, DCMA ensures a logistician or quality assurance individual is integrated on a contract from start to finish for better oversight and proactive resolution. NASA does not fully utilize its logistics personnel for Artemis programs. Separately, NASA could better utilize DCMA's contract administration capability to improve its overall supply chain management. Contract administration is an important component of supply chain management, given that supply chain management should occur throughout a program's life cycle. Effective contract administration can improve supply chain management by mitigating risks and improving relationships with suppliers. To this end, DCMA has extensive experience administering complex contracts on behalf of other agencies with defense suppliers, many of whom also supply NASA. While both DCMA and NASA officials are often physically located in a contractor's facility, DCMA officials told us the biggest advantage that DCMA has over NASA when it comes to contract administration is that, unlike NASA, DCMA is not the buying authority (e.g., Navy, Army, Air Force). According to DCMA officials, this lack of buying authority allows for a more independent assessment of a contractor's progress and performance, including management of its subcontractors and suppliers.

According to DCMA representatives, NASA does not effectively utilize DCMA expertise to perform full or partial contract management at a minimal cost. To its credit, NASA has been working with DCMA since 2021 to develop a Memorandum of Understanding to better align expectations and responsibilities between the two agencies with respect to contract administration services. One priority of the memorandum is to better leverage DCMA's capabilities, specifically in identifying supply chain risks.

European Space Agency. The European Space Agency (ESA) has several supply chain management methods from which NASA could learn. These include centralized Artemis project management support, periodic assessment of key suppliers, and contractual requirements for prime contractors to report suppliers. ESA officials specifically noted that the close physical proximity of its Artemis program and project management personnel is beneficial for information sharing about supplier issues and a stark contrast to NASA's approach, in which Artemis programs are spread across multiple Centers.

Automobile Manufacturing Industry. U.S. automobile manufacturers use various techniques to proactively manage their supply chains. In response to the global microchip shortage and other COVID-19 pandemic-related disruptions, one automaker emphasized improved monitoring systems. This involved identifying the most important links in the supply chain, flagging issues in real time, and investing in digital tools to track signals, all of which was overseen by a newly created team with a codified governance structure and process. In the industry as a whole, enhanced visibility into lower tiers of supply chains to identify "bottleneck suppliers" was identified as a critical capability.

We made several recommendations to NASA to be more proactive in supply chain monitoring and management for the Artemis effort. For example, to improve NASA's management and visibility into its supply chain, we recommended the Executive for the Supply Chain Resiliency Forum (1) establish a charter for the existing Supply Chain Resiliency Forum, (2) complete the Supply Chain Visibility Data Requirement Description effort, and (3) provide training to ensure contracting officers will utilize available supplier data.

3. Congress established statutory reporting requirements for NASA when major program developments breach certain cost and schedule growth thresholds. To what extent is the statutory reporting requirement effective in providing transparency to Congress on cost and schedule growth?

RESPONSE: NASA has nullified the effectiveness of reporting requirements of Title 51 of the United States Code, "National and Commercial Space Programs," specifically those requiring development cost reporting in the Major Program Annual Report and the 15 percent and 30 percent breach reporting requirements. NASA's new policy (NPR 7120.5F) allows single-project programs and projects that have an unspecified end point that plan for ongoing production and operations (for example, the SLS, Orion, and Exploration Ground Systems Programs) to establish cost estimates and commitments for only the individual program's initial capability and any major capability upgrades. As a result, there is no reporting of cost and schedule baselines for the SLS or Exploration Ground Systems beyond Artemis I and there will be no reporting for Orion beyond Artemis II. We believe this approach severely diminishes cost and schedule transparency and Congress's ability to monitor program implementation. Although we made several recommendations in our April 2022 report (IG-22-011) for NASA to establish cost and schedule baselines and be more transparent in reporting these to Congress, the Agency disagreed.

a. What more, if anything, needs to be done to improve transparency on cost and schedule for Artemis program developments?

RESPONSE: In light of NASA's new policy that further limits transparency into the Artemis campaign's cost and schedule, Congress should consider directing NASA to establish formal cost and schedule commitments for each Artemis mission (Artemis II, III, IV, etc.) in accordance with Title 51, which would be consistent with other major Agency programs and projects. Doing so would then allow Congress to better monitor the progress of each mission against a set of cost and schedule criteria and subject the mission to the 15 percent and 30 percent reporting thresholds and applicable review.

Questions submitted by Rep. Mike Garcia

1. If NASA chooses to cut Mars Sample Return funding to $300 million annually—nearly 1/3 of Congressionally appropriated levels—are you confident that the United States can beat China in the race to return a sample from Mars? How would any significant delay in the Mars Sample Return Mission affect the United States' goal of being the first nation to set foot on Mars?

RESPONSE: We believe potential cuts to the Mars Sample Return mission would have a negative impact on NASA's ability to maintain the mission's current architecture plan and schedule. However, NASA's Mars sample return approach is significantly different from China's effort in that the Agency is intending to return samples that are specifically of the highest value to the scientific community. That said, any delay in NASA's next step(s) in its overall understanding and exploration of Mars will have a cascading effect on its ability to and timeline for achieving a human presence on the surface of Mars.

Questions submitted by Rep. Darrell Issa

1. NASA has used fixed-price commercial contracts to save billions of dollars on other programs like Space Station crew and cargo transportation, as well as the Human Landing System Program. In an October 2023 report, you stated that "failure to achieve substantial savings will significantly hinder the sustainability of NASA's deep space human exploration efforts." Would you please explain why fixed-price commercial contracts have not been utilized throughout the Artemis program?

RESPONSE: In the NASA Authorization Act of 2010, Congress directed NASA to incorporate preexisting Constellation-era contracts and modify heritage equipment from the Space Shuttle and Constellation Programs in developing the SLS, Orion, and Mobile Launcher 1 As such, these large development contracts—the SLS's stages, boosters, and engines; Orion's capsule; and the Mobile Launcher for Artemis I through III—were sole sourced, eliminating any potential cost benefits of competition. Competing follow-on awards for production several years later became a non-starter due to the high cost of a new contractor instituting its own manufacturing processes and building facilities. NASA continued to use a cost-plus contracting structure for these key systems despite moving into production efforts for established systems designs, like the RS-25 engines and Orion capsule. NASA and its industry partners were unable to negotiate fixed-price contracts for these production efforts due to contractor concerns about cost uncertainty. Other efforts under the Artemis campaign are new design and development efforts, like the Mobile Launcher 2 which is a cost-type contract.

Despite the Agency's use of cost-plus contracting structures for these systems, NASA is moving to a service-based procurement approach in several key components of Artemis including the Human Landing Program, EPOC for the SLS, spacesuits, and portions of the Gateway.

a. Additionally, during the hearing, you shared that NASA had been challenged with the establishment of credible costs and schedule estimates, and agreed with me in saying that they have not met that challenge. Is that due to contractors not living up to their original promise or is it NASA's tendency to start a project and change the metrics—even on "new" goals that have previously been accomplished such as orbiting and landing on the moon?

RESPONSE: Our work has shown a number of factors contributed to the Agency's challenge of establishing credible cost and schedule estimates. These include mission and requirements changes from successive administrations, contractor underperformance, and NASA's failure to establish realistic and transparent cost and schedule baselines.

While the various components of the Artemis campaign have experienced requirements changes, perhaps the most significant impact has come from changes in successive administrations' space exploration priorities. SLS, Orion, and Exploration Ground Systems all began under the Constellation Program which had the initial goal of returning humans to the Moon by 2020. When the Constellation Program was canceled in 2010 in favor of a non-lunar focus, NASA was directed to continue development of Constellation's major components—the rocket, crew capsule, and launch facilities—without clearly defined missions or objectives. Under the next administration NASA was again directed to focus on lunar exploration. These pivots in space exploration goals resulted in changes to systems requirements, ultimately leading to cost increases and schedule delays. Our work has shown the cost and schedule impacts of the requirements changes from Constellation to Artemis on the SLS, Orion, and Mobile Launcher. Compounding the issue, contractors have, in most cases, underperformed and underestimated the complexity of incorporating these changes, further contributing to cost increases and schedule delays.

What's more, given the uncertainty in destination and future requirements of these systems, NASA elected to manage them as separate "capability demonstrations" and made cost and schedule commitments to Congress only to demonstrate the initial capability. Despite the continued focus on Artemis over the last two administrations, NASA continues to manage the key systems as separate capabilities and still lacks established cost and schedule commitments for the Artemis campaign as a whole or individual missions.

2. Because NASA has previously sent missions to the Moon—with much less sophisticated technology and knowledge—I am perplexed by the setbacks we are experiencing. Can time delays and cost overruns be attributed to an attempt to over-complicate a known process with new technology?

RESPONSE: We recommend referring this question to the appropriate NASA officials. They would be in better position to discuss the technology requirements needed to safely transport astronauts to and from the lunar surface as well as the establishment of a permanent human presence as envisioned by the Artemis campaign.

Questions submitted by Rep. Rich McCormick

1. While NASA has taken steps to improve the cost and schedule performance of its major programs, history tells us that it is likely that one of the new Artemis programs could struggle to meet its cost and schedule baselines, which could stretch NASA's available budget. How does NASA plan to maintain to sufficient cost and schedule margin to mitigate possible overruns and avoid a cascading effect onto other important programs?

RESPONSE: NASA has several affordability initiatives underway that it hopes will help reduce costs in the future. Success in these affordability issues would better position the Agency to maintain sufficient cost and schedule margin to mitigate possible overruns of a particular Artemis program and avoid a cascading effect onto other important programs. However, our recent work has shown that some key cost reduction efforts may fall short of expectations. For example, in May 2023 (IG-23-015) we reported that NASA is projecting manufacturing cost savings of 30 percent per engine for the SLS starting with production of the seventh of 24 new RS-25 engines. However, these projected savings do not capture overhead and other costs associated with restarting production of the engine, which we estimated to reach $2.3 billion. Likewise, in October 2023 (IG-24-001) we reported on NASA's efforts to reduce the cost of lunar missions beyond Artemis IV by transitioning management of multiple contractors for production of SLS systems and hardware, as well as systems integration and launch services, to a single contractor service. We found this approach would likely not achieve its cost reduction goals due to a variety of unrealistic assumptions, such as finding customers outside of NASA to use the SLS. Additionally, NASA aims to make its Moon to Mars plan more sustainable by sharing costs with its international partners. However, in January 2023 (IG-23-004) we reported that NASA's cost-sharing strategies with its international partners are still evolving and the Agency lacks an overall architecture, or blueprint, that includes cost estimates and responsibilities for international partners beyond Artemis IV.

To help ensure Congress is aware of possible overruns of a particular program and their potential impact on other programs' cost and schedule margin, it is important that NASA is transparent about Artemis costs and schedules. To this end, in accordance with Tile 51, NASA should set baselines and establish realistic cost and schedule estimates for each project, program, and mission within the Artemis campaign.

2. In your opinion how has Congress failed to fully support NASA in reaching their goals of the Artemis mission in a timely manner?

RESPONSE: While Congress has generally been supportive of NASA reaching its goals of the Artemis campaign, it can continue its support by providing stable and sufficient funding. Funding instability includes situations in which a project receives less money than planned or funds are disbursed on a schedule different than planned. Funding instability can result in inefficient management practices that contribute to poor cost, schedule, and performance outcomes. For example, inadequate funding in the early phases of a project's life cycle decreases management's ability to identify and address key risks at project inception. Moreover, in the absence of sufficient funding, program managers may have to defer the development of critical technologies to a time when integration of those technologies may be more difficult or when the costs of material and labor may be greater. In some cases, shifting tasks to later project phases may require managers to sustain a workforce longer than originally planned or add shifts in an attempt to make up for lost time, both of which can lead to increased costs and schedule delays.

a. How has NASA failed in implementing this program which has led to increased delays?

RESPONSE: Artemis is an extremely ambitious and costly endeavor involving several technically complex systems that need to come together for success. While we believe NASA must continue to look for ways to reduce costs and make the effort more sustainable, it is likely that a development effort of this magnitude will encounter cost increases and schedule delays through implementation. As such, it is critical that NASA establish credible, complete, and transparent cost and schedule estimates from which they can measure success and be accountable to Congress and other stakeholders. However, NASA has not established life-cycle costs nor made cost and schedule commitments for some of the programs supporting the Artemis campaign. By failing to do so, the Agency

is circumventing congressional requirements for reporting and tracking the costs of its Artemis missions. With better cost and schedule transparency, Congress will be in a better position to weigh the benefits of Artemis versus other NASA priorities.

b. How can Congress and NASA foster better coordination and transparency so that we can partner in achieving the ambitious goals of the Artemis mission?

RESPONSE: Congress can support NASA in reaching its Artemis goals by providing stable and sufficient funding, and NASA can increase transparency with Congress and other stakeholders by establishing formal cost and schedule commitments in accordance with Title 51. Doing so would allow Congress and NASA to monitor the progress of each mission against a set of cost and schedule criteria and subject the mission to the 15 percent and 30 percent reporting thresholds and applicable review, and thereby inform their decisions with respect to appropriations.

Responses by Dr. Michael D. Griffin

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

Returning to the Moon – Keeping Artemis on Track

17 January 2024

Questions for the Record

Dr. Michael D. Griffin,
Co-President
LogiQ, Inc.

Questions submitted by Chairman Brian Babin

1. The NASA IG reported that a single launch of the Space Launch System will cost $4.1 billion. Can you explain the difference between the cost of a single launch vehicle procurement and the costs associated with a program like SLS, which includes the cost of the entire infrastructure and workforce to enable not just SLS, but other contractor operations as well?

To be clear, I have no direct information on how the NASA budget is allocated across the various programs today. However, while I expect that the $4.1 B "cost" of a single SLS launch is technically correct, it is enormously misleading. I believe it likely that the cited cost includes the SLS program "share" of the entire NASA human spaceflight program and all the NASA Centers that support it. The decision by the United States to own and execute a human spaceflight program necessarily includes both fixed and variable costs. The fixed costs – personnel, contractor and NASA infrastructure, etc. – must be paid whether SLS (or any other vehicle) launches or not. Allocating those fixed costs to a single launch is not wrong, but it is not informative.

The more informative question to be asked of the NASA IG, or more properly the NASA CFO, concerns the variable or marginal cost of a single launch. Specifically, what is the cost of a single shipset of SLS hardware and that of the team that is required to execute a launch? Note, this is not the cost of keeping the launch team on staff, or the cost of the infrastructure that allows a shipset of hardware to be produced, but only the cost associated with that single shipset and the time necessary to launch it.

There is a good analogy here to the Shuttle Program. While I was last at NASA, an accepted figure for the marginal cost of a single Shuttle launch was about $300 M in 2005 dollars. However, the cost of maintaining NASA's human spaceflight program – with all of its facilities, infrastructure, and people – was around $10 B. If we launched three times in a given year, it would not be technically incorrect to say that each launch cost over $3 B, rather than the approximately $300 M that I cite above. But while it would not be "wrong", it would also not be a useful number to guide decision making about whether or not to launch another Shuttle mission in a given year.

Summarizing, the way to reduce the marginal cost of an SLS launch is to conduct a robust program of human spaceflight, focusing on pioneering the exploration of the Moon and the establishment of a lunar base thereupon. With such a program as the centerpiece of NASA, we would be using the SLS and any other heavy lift capacity that industry can provide to the fullest extent, thus more fully and appropriately utilizing the NASA human spaceflight infrastructure that has been built over the last 65 years.

Questions submitted by Rep. Mike Garcia

1. You spoke during the hearing about how throughout history, world powers have always been on the forefront of exploration. If China were to beat the United States to returning samples from the surface of Mars, how would it affect the US's standing on the global stage?

It is impossible to say how people would react to such an event, but in my judgment it would be very damaging to U.S. prestige in much the same way as the launch of Sputnik in 1957. In my opinion, progress on the space frontier with both human and robotic missions is a yardstick – not the only one, but a significant one – that the lesser nations of the world use to compare the great powers and to align their own actions accordingly.

Questions submitted by Rep. Dale Strong

1. Describe the unique capabilities of SLS that set it apart from other launch vehicles available and in development worldwide, and how these capabilities position the U.S. in the international space exploration arena.

The SLS is presently the world's only flight-proven heavy-lift launch vehicle, by which I mean a vehicle capable of providing *at least* several tens of metric tons of payload to a trans-lunar trajectory. As such, it is critical to the future of U.S. human space exploration and in particular for human lunar missions. Its development should be continued to obtain the maximum possible capability of the system.

This not to say that NASA should not use other spacelift capacity as it may develop over the ensuing years. It should be understood that if the U.S. chooses, as it should, to once again be the unquestioned leader on the space frontier, we will need all the heavy-lift capacity that the nation's industry can supply. But the SLS is the vehicle we have today and we should make the most of the taxpayer funding that went into developing it.