COMMITTEE ON
SCIENCE, SPACE AND TECHNOLOGY
CHAIRMAN BRIAN BABIN

SUBCOMMITTEE ON SPACE & AERONAUTICS

HEARING CHARTER

Step by Step: The Artemis Program and NASA's Path to Human Exploration of the Moon, Mars, and Beyond

Wednesday, February 26, 2025
10:00 A.M.
2318 Rayburn House Office Building

Purpose

The purpose of this hearing is to review outside perspectives of National Aeronautics and Space Administration (NASA) progress on the Artemis program and hear from witnesses about the importance of maintaining the continuity of purpose for NASA's human exploration program. This hearing will assess how the strategy and goals behind NASA's human exploration program have evolved over time from the Vision for Space Exploration to the current Moon to Mars Architecture. The Committee will also consider whether NASA can leverage developments in United States space capabilities to achieve Artemis objectives in a faster and more cost-effective manner. Finally, the hearing will address how today's efforts are directly tied to NASA's future exploration goals, including a crewed mission to Mars.

Witnesses

- **Dr. Scott Pace,** Director of Space Policy Institute, George Washington University
- **Mr. Dan Dumbacher,** Adjunct Professor, Purdue University

Overarching Questions

- What is the status of various elements of Artemis?
- How can Artemis architecture evolve to reduce costs and avoid additional delays?
- How does Artemis help ensure U.S. competitiveness in science and technology?
- What are the Chinese Communist Party's plans for sending astronauts to the Moon?

Background

Human space exploration has been a key NASA tenet since the agency's inception. One of NASA's greatest achievements was conducting a series of lunar landings between 1969 and 1972. NASA was able to achieve its goal of putting Americans on the Moon due, in large part, to clear and consistent direction from the federal government matched with substantial funding. While NASA funding is unlikely to reach Apollo-era levels in the near term, Congress can and should provide clear and consistent direction on the future of human space exploration.

In the decades since the Apollo program, United States human space activity was limited to low Earth orbit. NASA continued to carry out impressive feats, including the Skylab, International Space Station, and Space Shuttle programs. But NASA has not attempted to send astronauts into "deep space" since Apollo 17.

Today's Artemis program is a product of years of debate over the appropriate focus of human space exploration efforts. Throughout such considerations, the importance of maintaining continuity of purpose and goals for human space exploration has been highlighted. For example, the 2014 National Academies Pathways to Exploration report stated that "frequent changes in the goals for U.S. human space exploration (in the context of the decades that will be required to accomplish them) dissipate resources and impede progress."[1] Additionally, the 2021 Aerospace Safety Advisory Panel annual report "stressed the importance of constancy of purpose and its role in the ability of the Agency to manage risk intelligently and proactively."[2]

Through the Artemis Program, NASA seeks to return humans to the lunar surface by leveraging commercial and international partnerships. In addition to promoting national interests, such as technological advancement and economic competitiveness, returning to the Moon will allow NASA to establish best practices and advance scientific research and develop technologies needed to enable future crewed missions to Mars and other deep space destinations.

Evolution of the Artemis Program

The Artemis program and its systems reflect over several decades of study and policymaking related to U.S. human space exploration.

In 2004, President George W. Bush and NASA Administrator Sean O'Keefe released the Vision for Space Exploration, which sought to "extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations."[3] The plan also provided a generalized vision that the Administrator could use to "implement an integrated, long-term robotic and human exploration program structured with measurable milestones and executed on the basis of available resources, accumulated experience, and technology readiness." The same year, Congress passed the NASA Authorization Act of 2005 which directed NASA to "establish a program to develop a sustained human presence on the Moon […] to promote exploration, science, commerce, and United States preeminence in space, and as a stepping-stone to future exploration of Mars and other

[1] National Academies of Science, Engineering, and Medicine, *Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration,* 2014. Retrieved at https://nap.nationalacademies.org/catalog/18801/pathways-to-exploration-rationales-and-approaches-for-a-us-program
[2] NASA Aerospace Safety Advisory Panel, *2021 Annual Report,* January 2022. Retrieved at https://www.nasa.gov/asap-reports/
[3] National Aeronautics and Space Administration, *The Vision for Space Exploration,* February 2004. Retrieved at http://www.nasa.gov/pdf/55583main_vision_space_exploration2.pdf

destinations."[4] Under the Constellation program, NASA began developing exploration hardware to accomplish these goals, including the Ares launch vehicles, an Earth Departure Stage secondary booster, an Orion spacecraft, and an Altair lunar lander.

Despite clear and consistent Congressional support for Constellation during the Bush Administration, on May 7, 2009, President Obama released his presidential budget request (PBR) for Fiscal Year 2010. This budget request cut funding to the exploration account, which included Constellation, by roughly $1 billion per year in the outyears (starting in Fiscal Year 2011).

The same day that the Administration announced it was cutting the budget for Constellation, Dr. Holdren, the President's Science Advisor and Director of the White House Office of Science and Technology Policy, sent a letter to NASA directing the initiation of a "review of ongoing U.S. human spaceflight plans and programs," to see if the program was "sustainable."[5] The final report, titled the "Review of U.S. Human Spaceflight Plans Committee," was chaired by Norman Augustine (commonly referred to as the "Augustine Report."). The Commission released its final report on October 22, 2009.[6]

The primary conclusion of the report was that the current program was "unexecutable."[7] After the Obama Administration reduced funding for the Constellation program, it was not surprising that the Augustine Commission found that the program was underfunded.[8] Despite this, one of the panel members, retired Air Force General Lester Lyles, found that "The current program of record, in my opinion, seems to be the right one."[9] However, based on the Obama Administration's budget request, the report found that "[h]uman exploration beyond low Earth orbit is not viable under the [fiscal] 2010 budget guideline."[10]

Despite this, the Obama Administration canceled Constellation in 2010 and instead opted to pursue a crewed mission to an asteroid as a predecessor to an eventual Mars mission. During the same period, Congress passed the NASA Authorization Act of 2010, reaffirming the commitment to human space exploration, preserving some elements of the Constellation program, including the Orion spacecraft, and initiating development of the Space Launch System (SLS) rocket.[11]

In 2017, the Trump Administration directed NASA to "lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other

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[4] National Aeronautics and Space Administration Authorization Act of 2005 (P.L. 109-155)
[5] Office of Science and Technology and Policy, *Letter -- OSTP Director John Holdren to NASA Acting Administrator Chris Scolese,* May 2009. Retrieved at: https://obamawhitehouse.archives.gov/the-press-office/2015/11/16/letter-ostp-director-john-holdren-nasa-acting-administrator-chris
[6] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, October 2009. Retrieved at https://www.nasa.gov/wp-content/uploads/2015/01/617036main_396093main_hsf_cmte_finalreport.pdf?emrc=e76114
[7] See Supra 6
[8] Foust, Jeff, "Lyles on Constellation, commercialization, and organization," Space Politics, October 20, 2009. Retrieved at http://www.spacepolitics.com/2009/10/20/lyles-on-constellation-commercialization-and-organization/
[9] Klamper, Amy, "NASA in Limbo as Augustine Panel Issues Final Report," SpaceNews, October 23, 2009, Retrieved at http://spacenews.com/nasa-limbo-augustine-panel-issues-final-report/
[10] See Supra 6
[11] National Aeronautics and Space Administration Authorization Act of 2010 (P.L. 111-267)

destinations."[12] The NASA Transition Authorization Act of 2017 reiterated Congress's support for the stepping stone approach to space exploration and directed NASA to establish a human exploration roadmap.[13] The Act also directed NASA to continue development of SLS and Orion to enable human exploration of the Moon, Mars, and beyond. The following year, NASA issued a National Space Exploration Campaign Report setting forth the "roadmap" requested by Congress, and detailing the Agency's plan for human space exploration, which included a crewed lunar landing by the late 2020s.[14]

During his Administration, President Biden chose to continue the Artemis program, and in late 2021, released a United States Space Priorities Framework that reaffirmed the commitment to send humans to the Moon as a step towards future missions to Mars and other deep space destinations.[15] In 2022, Congress provided further direction to NASA via the CHIPS and Science Act. Specifically, Congress directed NASA to establish a new Moon to Mars Program Office within the Exploration Systems Development Mission Directorate (ESDMD), charged with managing hardware development, mission integration, and risk management for Artemis. The office was also directed to ensure that Artemis activities demonstrated capabilities to facilitate eventual human missions to Mars. [16]

Artemis Elements

The Artemis program involves a number of NASA programs and projects mainly managed within ESDMD, although the Space Technology Mission Directorate (STMD) and Science Mission Directorate (SMD) also manage some elements. Additionally, both the U.S. private sector and international governments are contributing to Artemis in various ways. Core Artemis mission elements include:

Space Launch System (SLS). SLS is a two-stage, super heavy-lift launch vehicle that will launch the Orion spacecraft. NASA plans for three different SLS configurations (Block 1, 1B, and 2) with each configuration resulting in an eventual 130 metric tons to low Earth orbit capability. Between Block 1 and 1B, the Interim Cryogenic Propulsion Stage (ICPS) will be replaced with the Exploration Upper Stage (EUS). Additionally, Block 2 will replace the solid rocket boosters with an upgraded model.

Orion Spacecraft. The Orion multipurpose crew vehicle is a spacecraft capable of supporting crew exploration in deep space for up to 21 days. Orion consists of three main components: a crew module, a service module, and a launch abort system. For Artemis, Orion will carry the crew to lunar orbit and return them safely to Earth.

Exploration Ground Systems (EGS). EGS manages the development and operation of Kennedy Space Center systems and facilities that support modern and next generation launch

[12] President Donald Trump, *Space Policy Directive-1, Reinvigorating America's Human Space Exploration Program,* December 2017. Retrieved at https://trumpwhitehouse.archives.gov/presidential-actions/presidential-memorandum-reinvigorating-americas-human-space-exploration-program/
[13] National Aeronautics and Space Administration Transition Authorization Act of 2017 (P.L. 115-10)
[14] National Aeronautics and Space Administration, *National Space Exploration Campaign Report*, September 2018. Retrieved at https://www.nasa.gov/wp-content/uploads/2015/01/nationalspaceexplorationcampaign.pdf?emrc=dd952c
[15] President Joseph Biden, *United States Space Priorities Framework*, December 2021. Retrieved at https://bidenwhitehouse.archives.gov/wp-content/uploads/2021/12/United-States-Space-Priorities-Framework-_-December-1-2021.pdf
[16] CHIPS and Science Act (P.L. 117-167)

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.

Human Landing System (HLS). The HLS is a lunar landing system that will dock either with Gateway or Orion and transport astronauts from lunar orbit to the surface of the Moon and back to lunar orbit. NASA awarded contracts for development of lunar landers to two U.S. commercial providers, SpaceX and Blue Origin.[17]

Gateway. Gateway is a Moon orbiting space station that will provide a staging point for lunar expeditions and deep space exploration, as well as a platform for scientific research and technology demonstrations. NASA plans to launch the first two Gateway modules, the Power and Propulsion Element and Habitation and Logistics Outpost, to create an initial capacity while adding more modules later to expand its capabilities. The Gateway will involve international contributions including additional habitation, external robotics, and refueling capability.

Spacesuits. 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. In June 2022, NASA awarded a contract to Axiom Space to produce new suits for Artemis via the Exploration Extravehicular Activity Services (xEVAS) program.[18]

Artemis Missions

The Artemis program consists of sequentially numbered missions that utilize exploration elements, such as SLS and Orion, to access deep space destinations, including lunar orbit, Gateway, and/or the lunar surface.

[17] National Aeronautics and Space Administration, *About Human Landing Systems Development.* Retrieved at https://www.nasa.gov/reference/human-landing-systems/

[18] National Aeronautics and Space Administration, *NASA Taps Axiom Space for First Artemis Moonwalking Spacesuits,* September 2022. Retrieved at https://www.nasa.gov/news-release/nasa-taps-axiom-space-for-first-artemis-moonwalking-spacesuits/

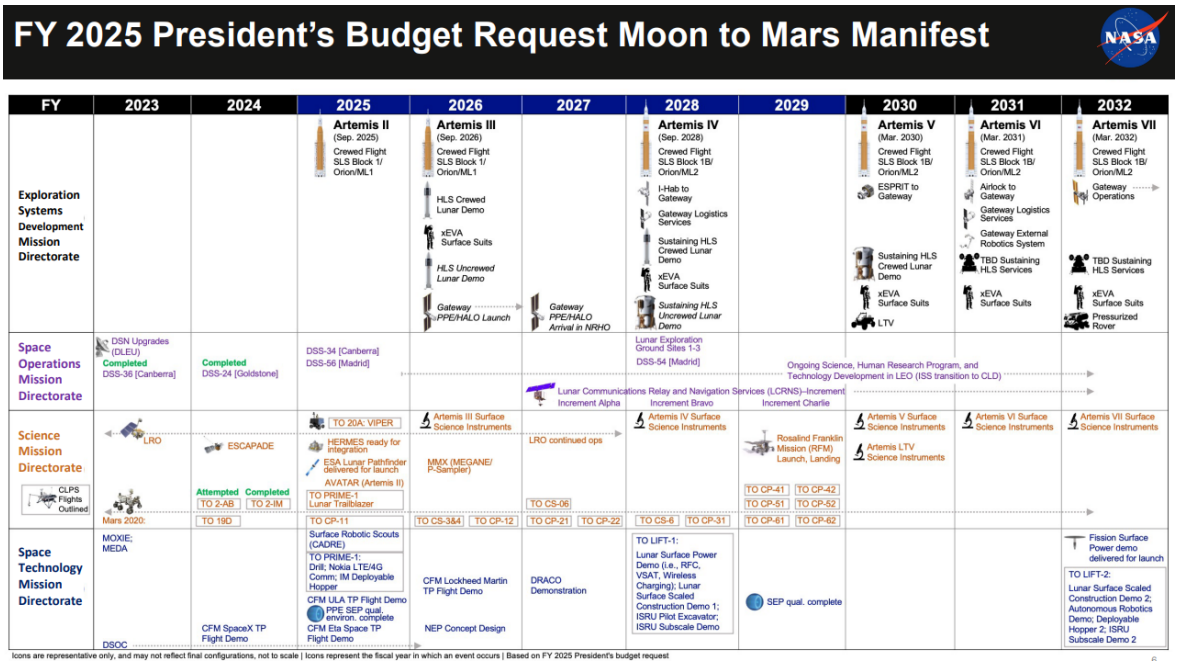

Figure 1: NASA Moon to Mars Manifest. (Source: NASA) [Note: This figure does not reflect the most recent delays for Artemis II and III to April 2026 and mid-2027 respectively.]

Artemis I was an uncrewed demonstration mission that launched out of Kennedy Space Center on November 16, 2022. Originally scheduled for November of 2018, the mission was the first test of the fully integrated SLS, Orion, and EGS systems and conducted two lunar flybys over the course of its 25-day mission before returning to Earth. Post-flight analysis indicated that the mission was successful and many systems performed better than expected,[19] but also flagged issues, including unexpected char loss on the Orion heatshield, that required further investigation.[20]

Artemis II will be the first crewed demonstration flight of the integrated SLS, Orion, and EGS systems. During the mission, which will conduct a flyby of the far side of the Moon, the crew will conduct verification testing on the spacecraft systems and evaluate the spacecraft's performance in deep space. The crew includes NASA astronauts Reid Wiseman, Victor Glover, and Christina Koch as well as Canadian Space Agency astronaut Jeremy Hansen. The mission is currently expected to launch in April 2026.

Artemis III will be a crewed lunar landing demonstration mission and the first crewed mission to the lunar surface. The crew will launch aboard the integrated SLS and Orion spacecraft to a lunar orbit where they rendezvous with the HLS. The HLS will then transport two crew members to the surface for one week during which they will perform a range of tasks including scientific experiments and technology demonstrations. After which, the HLS will return the crew to the Orion spacecraft in lunar orbit before returning to Earth. The mission is currently planned for mid-2027.

[19] National Aeronautics and Space Administration, *Analysis Confirms Successful Artemis I Moon Mission, Reviews Continue,* March 2023. Retrieved at https://www.nasa.gov/humans-in-space/analysis-confirms-successful-artemis-i-moon-mission-reviews-continue-2/

[20] National Aeronautics and Space Administration, *NASA Identifies Cause of Artemis I Orion Heat Shield Char Loss,* December 2024. Retrieved at https://www.nasa.gov/missions/artemis/nasa-identifies-cause-of-artemis-i-orion-heat-shield-char-loss/

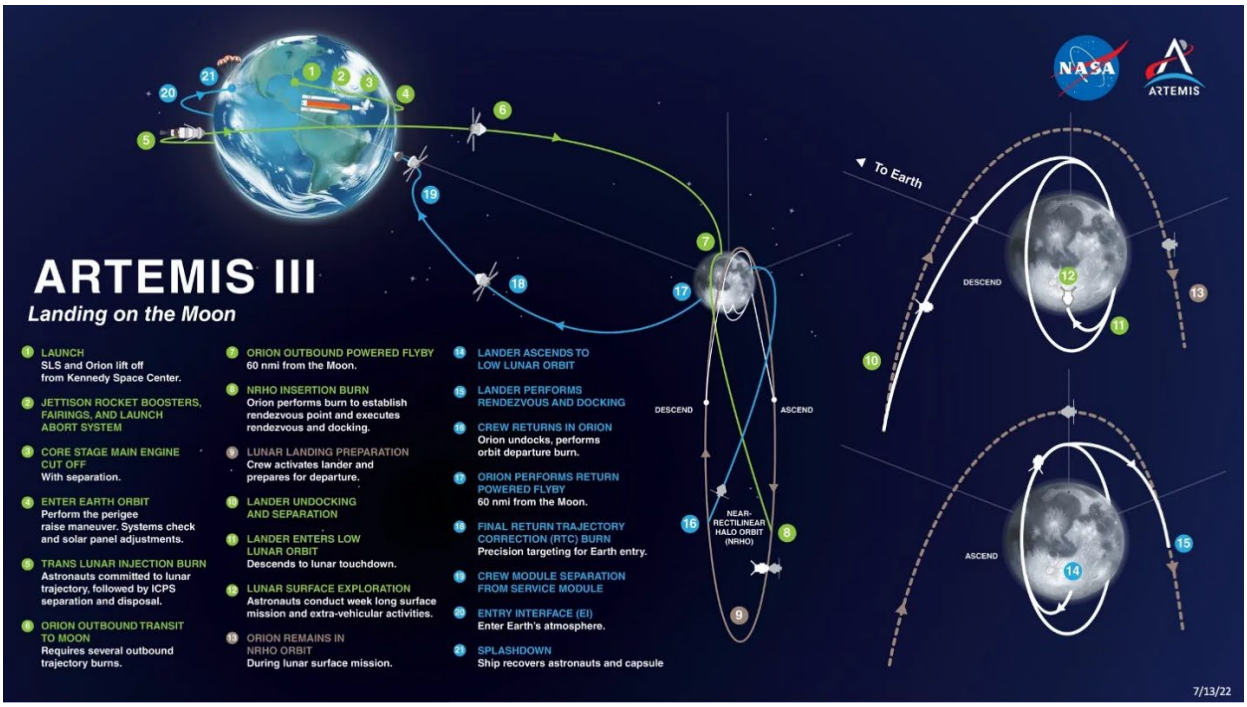

Figure 2: Artemis III Mission Map. (Source: NASA)

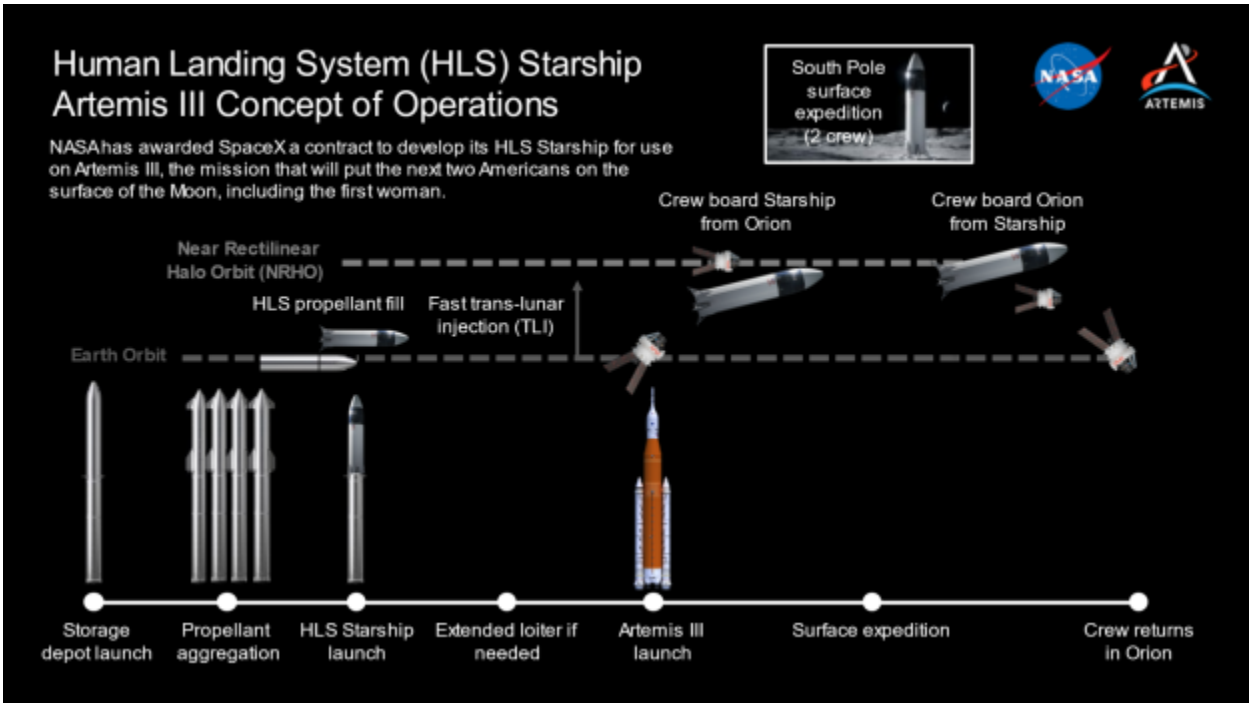

Figure 3: Artemis III HLS Concept of Operations. (Source: NASA)

Artemis IV will be the second crewed lunar landing mission and the debut of the Block 1B variant of SLS. During the mission, Orion will transport the crew as well as the I-Hab module to lunar orbit. The module will then be delivered to Gateway after which two crew members will travel to the lunar surface aboard HLS for a week of surface operations, including sample collection, before returning to Earth.

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

As the Artemis program progresses, NASA intends to establish an annual launch cadence for SLS with "at least one crewed flight per year for the next 10 or more years."[21] To support this schedule the Agency began to establish long-lead contracts for SLS, including for solid rocket boosters, core stages, and RS-25 engines.

Artemis Budget

The Artemis program is primarily funded through the Deep Space Exploration Systems budget line. The following provides an overview of the budget for the program:

Budget Authority ($ in millions)	Op Plan 2023	CR 2024	Request 2025	2026	2027	2028	2029
NASA Total	**25,383.7**	**25,383.7**	**25,383.7**	**25,891.3**	**26,409.1**	**26,937.3**	**27,476.1**
Deep Space Exploration Systems	**7,447.6**	**7,468.9**	**7,618.2**	**7,803.7**	**7,959.8**	**8,119.0**	**8,281.4**
Moon to Mars Transportation System	**4,716.6**	**--**	**4,213.0**	**4,254.0**	**4,267.3**	**3,880.9**	**3,713.6**
Orion Program	**1,315.1**	**--**	**1,031.0**	**1,176.9**	**1,288.5**	**1,266.4**	**1,166.4**
Crew Vehicle Development	1,301.5	1,221.0	1,023.5	1,141.9	1,281.0	1,213.7	1,113.8
Orion Program Integration and Support	13.5	--	7.5	35.0	7.5	52.7	52.7
Space Launch System	**2,566.8**	**--**	**2,423.2**	**2,379.0**	**2,402.9**	**2,072.3**	**2,026.8**
Block 1B Capability Upgrade	648.3	462.5	285.8	275.1	54.3	--	--
SLS Operations	1,844.4	--	2,028.4	1,972.0	2,240.5	1,899.8	1,853.8
SLS Program Integration and Support	74.0	--	109.0	131.9	108.1	172.5	173.0
Exploration Ground Systems	**834.8**	**--**	**758.8**	**698.1**	**576.0**	**542.3**	**520.4**
Exploration Ground Systems Development	330.6	356.2	235.8	148.3	31.4	--	--
EGS Program Integration and Support	504.2	--	523.0	549.8	544.6	542.3	520.4
Moon to Mars Lunar Systems Development	**2,630.5**	**--**	**3,288.1**	**3,285.7**	**3,389.5**	**3,868.8**	**3,712.3**
Gateway	**779.2**	**--**	**817.7**	**627.9**	**586.8**	**746.0**	**635.4**
Gateway Initial Capability	493.0	516.6	431.8	181.3	--	--	--
xEVA and Human Surface Mobility Program	**324.9**	**--**	**434.2**	**483.9**	**644.7**	**673.6**	**571.2**
Human Landing System	**1,386.1**	**--**	**1,896.1**	**2,050.9**	**1,994.9**	**2,278.3**	**2,334.7**
HLS Initial Capability	807.3	526.3	647.1	703.3	607.2	252.1	--
Advanced Exploration Systems	**140.3**	**--**	**140.2**	**123.0**	**163.1**	**170.9**	**171.0**
Human Exploration Requirements & Architecture	**100.5**	**--**	**117.1**	**264.1**	**303.0**	**369.3**	**855.5**
Strategy & Architecture	**48.3**	**--**	**71.2**	**137.4**	**64.1**	**65.5**	**66.7**
Future Systems	**52.2**	**--**	**45.9**	**126.7**	**238.8**	**303.8**	**788.8**

Figure 4: NASA Fiscal Year 2025 President's Budget Request. (Source: NASA)

[21] National Aeronautics and Space Administration, *NASA Seeks Input to Position Mega-Rocket for Long-Term Exploration,* October 2021. Retrieved at https://www.nasa.gov/missions/artemis/orion/nasa-seeks-input-to-position-mega-rocket-for-long-term-exploration/

Key Issues Identified in Recent Reports, Reviews, and Audits

Government Accountability Office (GAO)

NASA Artemis Missions: Exploration Ground Systems Program Could Strengthen Schedule Decisions[22]

In October 2024, GAO issued a report evaluating NASA management of the EGS program as well as reviewing the impact that EGS delays pose for the Artemis program. The concerns identified by GAO include the following:

- The one-year gap between Artemis II and III creates little schedule margin to mitigate challenges and technical issues as well as take corrective actions between the missions. This is particularly true for the Mobile-Launcher-1 (ML-1), which experienced an unexpected level of damage during the Artemis I launch and must be repaired again between Artemis II and III.

- The Mobile-Launcher-2 (ML-2) is the primary schedule driver for Artemis IV and its development has limited margin and significant risk. Additionally, the majority of the work related to ML-2 can only be accomplished after the launch of Artemis III which creates additional schedule risk. Despite this, NASA has not committed to conducting a schedule risk analysis for EGS and ML2 moving forward.

GAO recommended that NASA direct the Exploration Ground Systems program and Mobile Launcher 2 project officials to perform at least one schedule risk analysis prior to beginning integrated operation activities to support the Artemis IV launch.

NASA Inspector General

NASA's Management of Space Launch System Block 1B Development[23]

NASA Office of Inspector General (OIG) released a report in August 2024 that evaluated NASA's Management of SLS Block 1B development. The report found:

- Boeing's quality management system at Michoud does not effectively adhere to industry standards or NASA requirements which creates production delays to the SLS core and upper stages and increased risk to the integrated spacecraft. This is compounded by a lack of sufficient aerospace production experience among Boeing's Michoud workforce.

- The total costs for SLS Block 1B development are expected to reach $5.7 billion which is $700 million over the cost baseline.

- NASA delayed establishing the Block 1B Agency Baseline Commitment until December 2023, after 10 years of development and much later in the project life cycle than NASA's

[22] Government Accountability Office, *NASA Artemis Missions: Exploration Ground Systems Program Could Strengthen Schedule Decision,* October 2024, GAO-25-106943. Retrieved at https://files.gao.gov/reports/GAO-25-106943/index.html
[23] NASA Office of Inspector General, *NASA's Management of Space Launch System Block 1B Development,* August 2024, IG-24-015. Retrieved at https://oig.nasa.gov/office-of-inspector-general-oig/nasas-management-of-space-launch-system-block-1b-development/

standard practice. This delay limited NASA's ability to assess adherence to budgets and timelines, and Congress lacked visibility into the Block 1B's increasing costs and schedule delays.

NASA's Readiness for the Artemis II Crewed Mission to Lunar Orbit[24]

In May 2024 NASA OIG released a report reviewing NASA's preparedness for Artemis II, particularly given the issues that arose during the Artemis I mission in November 2022. The OIG found that:

- The Orion heat shield experienced unexpected ablative char loss during the Artemis I mission. While the char loss was unanticipated, NASA's post-mission investigation of the heat shield found that "thermal performance of the heat shield exceeded expectations."[25] Additionally, there was unexpected melting and erosion on the Orion Crew Module/Service Module separation bolts which created a gap leading to increased heating inside the bolt.

- NASA recorded 24 instances of power distribution anomalies in Orion's Electrical Power System. The Agency determined radiation was the root cause and is working on corrective actions. However, without a permanent hardware fix there is an increased risk of further power distribution anomalies on future missions.

- During Artemis I, SLS caused greater damage to ML-1 than expected. NASA set aside $5 million for post-Artemis launch repairs, but the actual damage is expected to cost more than $26 million to repair.

The OIG recommended that NASA:

- Ensure the root cause of Orion heat shield char liberation is well understood prior to launch of the Artemis II mission.

- Conduct analysis of Orion separation bolts using updated models that account for char loss, design modifications, and operational changes to Orion prior to launch of the Artemis II mission.

- Reexamine procedures to better ensure recovery of Orion jettisoned hardware for the Artemis II mission.

- Develop a corrective action plan to mitigate or prevent the recurrence of uninterpretable Orion telemetry data for the Artemis II mission

[24] NASA Office of Inspector General, *NASA's Readiness for the Artemis II Crewed Mission to Lunar Orbit,* May 2024, IG-24-011. Retrieved at https://oig.nasa.gov/office-of-inspector-general-oig/audit-reports/nasas-readiness-for-the-artemis-ii-crewed-mission-to-lunar-orbit/

[25] National Aeronautics and Space Administration, *NASA Identifies Cause of Artemis I Orion Heat Shield Char Loss,* December 2024. Retrieved at https://www.nasa.gov/missions/artemis/nasa-identifies-cause-of-artemis-i-orion-heat-shield-char-loss/

- Establish a course of action and timeline for individual Artemis system design changes before beginning integrated system assembly stacking operations.

NASA's Aerospace Safety Advisory Panel

Aerospace Safety Advisory Panel 2024 Annual Report[26]
The Aerospace Safety Advisory Panel (ASAP) is a congressionally mandated NASA advisory committee that conducts an annual review of the safety of NASA activities with a priority focus on human space flight safety. In the 2024 ASAP report, Artemis remained a continued focus.

The Panel raised concerns about the aggregated risk created by the large number of first-time milestones present in the Artemis III mission architecture given the current mission schedule and technical readiness of some elements, particularly HLS. The Panel also noted that NASA will need to craft an approach to Artemis program integration because of the number of service contracts and international contributions to the program and varied roles and responsibilities of each partner.

Additionally, the Panel suggested that NASA could strengthen Artemis Architectural Completeness and Risk Management. This includes formalizing a Design Reference Mission to define how a mission will be conducted, specifying objectives, the systems involved, and operational processes. As well as defining key mission objectives for each Artemis mission and ensuring the objectives are balanced across the program.

[26] NASA Aerospace Safety Advisory Panel, *2024 Annual Report,* February 2025. Retrieved at https://www.nasa.gov/asap-reports/