DEVELOPING CORE CAPABILITIES FOR DEEP SPACE EXPLORATION: AN UPDATE ON NASA'S SLS, ORION, AND EXPLORATION GROUND SYSTEMS

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE AND AERONAUTICS

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED SIXTEENTH CONGRESS

FIRST SESSION

SEPTEMBER 18, 2019

Serial No. 116–44

Printed for the use of the Committee on Science, Space, and Technology

Available via the World Wide Web: http://science.house.gov

U.S. GOVERNMENT PUBLISHING OFFICE
37–662PDF WASHINGTON : 2020

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HON. EDDIE BERNICE JOHNSON, Texas, *Chairwoman*

ZOE LOFGREN, California
DANIEL LIPINSKI, Illinois
SUZANNE BONAMICI, Oregon
AMI BERA, California, *Vice Chair*
CONOR LAMB, Pennsylvania
LIZZIE FLETCHER, Texas
HALEY STEVENS, Michigan
KENDRA HORN, Oklahoma
MIKIE SHERRILL, New Jersey
BRAD SHERMAN, California
STEVE COHEN, Tennessee
JERRY MCNERNEY, California
ED PERLMUTTER, Colorado
PAUL TONKO, New York
BILL FOSTER, Illinois
DON BEYER, Virginia
CHARLIE CRIST, Florida
SEAN CASTEN, Illinois
KATIE HILL, California
BEN MCADAMS, Utah
JENNIFER WEXTON, Virginia

FRANK D. LUCAS, Oklahoma, *Ranking Member*
MO BROOKS, Alabama
BILL POSEY, Florida
RANDY WEBER, Texas
BRIAN BABIN, Texas
ANDY BIGGS, Arizona
ROGER MARSHALL, Kansas
RALPH NORMAN, South Carolina
MICHAEL CLOUD, Texas
TROY BALDERSON, Ohio
PETE OLSON, Texas
ANTHONY GONZALEZ, Ohio
MICHAEL WALTZ, Florida
JIM BAIRD, Indiana
JAIME HERRERA BEUTLER, Washington
JENNIFFER GONZÁLEZ-COLÓN, Puerto Rico
VACANCY

SUBCOMMITTEE ON SPACE AND AERONAUTICS

HON. KENDRA HORN, Oklahoma, *Chairwoman*

ZOE LOFGREN, California
AMI BERA, California
ED PERLMUTTER, Colorado
DON BEYER, Virginia
CHARLIE CRIST, Florida
KATIE HILL, California
JENNIFER WEXTON, Virginia

BRIAN BABIN, Texas, *Ranking Member*
MO BROOKS, Alabama
BILL POSEY, Florida
PETE OLSON, Texas
MICHAEL WALTZ, Florida

C O N T E N T S

September 18, 2019

DEVELOPING CORE CAPABILITIES FOR DEEP SPACE EXPLORATION: AN UPDATE ON NASA'S SLS, ORION, AND EXPLORATION GROUND SYSTEMS

WEDNESDAY, SEPTEMBER 18, 2019

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 of the Rayburn House Office Building, Hon. Kendra Horn [Chairwoman of the Subcommittee] presiding.

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

HEARING CHARTER

Developing Core Capabilities for Deep Space Exploration: An Update on NASA's SLS, Orion, and Exploration Ground Systems Programs

Wednesday, September 18, 2019
10:00 a.m.
2318 Rayburn House Office Building

PURPOSE

The purpose of the hearing is to assess the status, including the progress, challenges, and other issues, of NASA's Exploration Systems Development programs (the Space Launch System, Orion Multipurpose Crew Vehicle, and Exploration Ground Systems).

WITNESSES

- **Mr. Kenneth Bowersox,** Associate Administrator (Acting), Human Exploration and Operations, National Aeronautics and Space Administration
- **Ms. Cristina Chaplain,** Director, Contracting and National Security Acquisitions, U.S. Government Accountability Office
- **Mr. Doug Cooke**, Owner, Cooke Concepts and Solutions; Former Associate Administrator, Exploration Systems, National Aeronautics and Space Administration

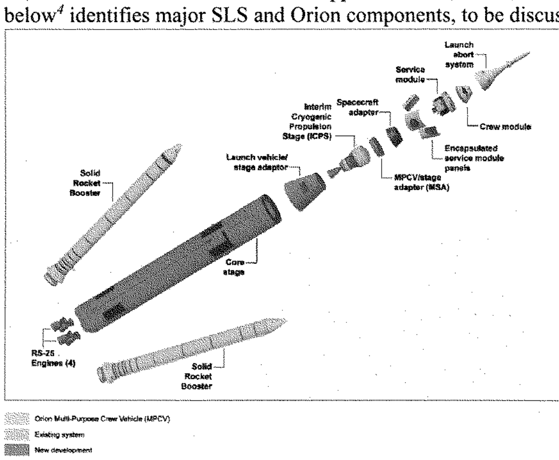
OVERARCHING QUESTIONS

- *What are current challenges and upcoming milestones for the Space Launch System (SLS), Orion, and Exploration Ground Systems (EGS) programs?*
- *What are the biggest drivers of cost growth and schedule challenges for the SLS, Orion, and EGS programs?*
- *How can Congress best ensure that schedule pressure does not compromise safety in the SLS, Orion, and EGS programs?*
- *What are NASA's plans for SLS and Orion after sending humans to the Moon in 2024?*

BACKGROUND

NASA is developing a new heavy-lift rocket and crew vehicle capable of returning humans to deep space—generally defined as anywhere beyond low Earth orbit (LEO), about 1,200 miles above the Earth's surface—for the first time since the last Apollo astronauts landed on the Moon in 1972. The agency is working under the directives of the NASA Authorization Act of 2010[1] to build a Space Launch System (SLS), "*the follow-on government-owned civil launch system developed, managed, and operated by NASA to serve as a key component to expand human presence beyond low Earth orbit,*" and continue building the Orion Multi-Purpose Crew Vehicle (Orion), "*to be available as soon as practicable, and no later than for use with the Space Launch System.*" Concurrently, through the Exploration Ground Systems (EGS) program, NASA is upgrading Kennedy Space Center (KSC) infrastructure and developing software for SLS and Orion integration, processing, and operations. SLS and Orion development has drawn on work from the Constellation program[2] and used some existing and refurbished Space Shuttle hardware.

According to NASA, Orion will be the "*only spacecraft capable of carrying and sustaining crew on missions to deep space, providing emergency abort capability, and safe re-entry from lunar return velocities,*" and SLS will be "*the only rocket with the power and capability required to carry astronauts to deep space on board the Orion spacecraft.*"[3] More than 3,800 suppliers and 60,000 workers across all 50 states support the SLS, Orion, and EGS programs. The figure below[4] identifies major SLS and Orion components, to be discussed further in what follows.



SLS and Orion Hardware. Source: Government Accountability Office (GAO)

The first fully integrated test of the SLS, Orion, and EGS system will be an uncrewed flight known as Exploration Mission 1 (EM-1, since Artemis 1). The SLS re-named rocket will launch the uncrewed Orion capsule to lunar orbit for a three-week mission; Orion will orbit the Moon for six days before returning to Earth.[5] The second flight, Exploration Mission 2 (EM-2, or Artemis 2), will carry up to four astronauts on board Orion to lunar orbit before returning them safely to Earth. The two flights will take different trajectories to demonstrate the full range of capabilities of SLS and

[1] Pub. L. No. 111-267, "National Aeronautics and Space Administration Authorization Act of 2010," Title II, Section 302. October 11, 2010. Available at: https://www.congress.gov/bill/111th-congress/senate-bill/3729
[2] NASA began the Constellation Program in response to President Bush's Vision for Space Exploration, and work included initial development of the Ares heavy-lift rockets and the Orion Crew Exploration Vehicle. In 2010, President Barack Obama proposed to cancel Constellation after an independent review found that the program was unsustainable given funding constraints, schedule realities, and goals of the agency.
[3] https://www.nasa.gov/sites/default/files/atoms/files/america_to_the_moon_2024_artemis_20190523.pdf
[4] GAO, "NASA HUMAN SPACE EXPLORATION: Persistent Delays and Cost Growth Reinforce Concerns over Management of Programs," June 2019. GAO-19-377. Available at: https://www.gao.gov/products/GAO-19-377
[5] https://www.nasa.gov/feature/around-the-moon-with-nasa-s-first-launch-of-sls-with-orion

Orion. In 2014 and 2015, NASA committed to launch EM-1 no later than November 2018 and EM-2 no later than April 2023, but later delayed EM-1 to no later than June 2020. However, in testimony to the House Subcommittee on Space and Aeronautics on May 8, 2019, NASA officials reported that June 2020 would no longer be possible.[6]

After the test flights, NASA intends to be able to launch human or large cargo payloads to deep space at a frequency of about once per year.[7] In the FY 2020 budget request submitted to Congress in March 2019, NASA outlined plans for multiple SLS/Orion/EGS missions to a Lunar Gateway, eventually leading to a 2028 lunar landing as part of establishing a sustainable human exploration infrastructure on and around the Moon. Two weeks after releasing the proposal, the Trump administration directed NASA to return humans to the lunar surface sooner, by 2024. NASA now plans to land humans on the Moon in 2024 on the third launch of SLS and Orion [the second crewed launch of Orion]. NASA has not released a definitive plan (schedule and/or destinations) for future SLS launches.

Overview of the Space Launch System (SLS)

SLS will be NASA's first deep space rocket since the Apollo-era Saturn V, and its most powerful. The minimum requirements set in the NASA Authorization Act of 2010 include:[8]

- An initial capability to lift payloads between 64 and 91 metric tons (mt) to LEO
- An eventual capability, with an enhanced upper stage, to lift payloads of 118 mt to LEO
- The capability to lift the multipurpose crew vehicle
- The capability to serve as a backup system for ISS crew and cargo delivery
- Flexibility in design to allow evolution in capability to carrying heavier payloads

NASA has designed SLS as a two-stage, super heavy-lift rocket that will evolve over three configurations with incrementally increasing capacity. The Block 1 configuration will be capable of lifting payloads of 70 mt to LEO (24 mt to the Moon, 20 mt to Mars). A planned Block 1B configuration will use an Exploration Upper Stage (EUS) to be capable of lifting 105 mt to LEO (40 mt to the Moon, 33 mt to Mars). Finally, the planned Block 2 configuration will use both the EUS and advanced solid rocket boosters and be capable of lifting 130 mt to LEO (52 mt to the Moon, 41 mt to Mars). SLS Block 1 will produce 8.8 million pounds of thrust at launch, 13 percent more than the Space Shuttle and 15 percent more than the Apollo-era Saturn V during liftoff and ascent.[9]

---

[6] Prepared Statement of William H. Gerstenmaier and Mark Sirangelo, "Keeping Our Sights on Mars: A Review of NASA's Deep Space Exploration Programs and Lunar Proposal," May 8, 2019. Available at: https://science.house.gov/imo/media/doc/Joint%20Gerstenmaier-Sirangelo%20Testimony.pdf

[7] IDA Science & Technology Policy Institute, "Evaluation of a Human Mission to Mars by 2033," March 2019. Available at: https://www.ida.org/-/media/feature/publications/e/ev/evaluation-of-a-human-mission-to-mars-by-2033/d-10510.ashx

[8] Title 42, U.S. Code, Section 18322, The Space Launch System as a follow-on launch vehicle to the Space Shuttle. Available at: https://www.law.cornell.edu/uscode/text/42/18322

[9] NASA, "NASA's Space Launch System: Meet the Rocket," July 21, 2014. Available at: https://www.nasa.gov/sls/multimedia/gallery/sls-infographic3.html

The SLS program is managed out of the Marshall Space Flight Center in Huntsville, Alabama, which reports to the Exploration Systems Development (ESD) division at NASA Headquarters. Manufacturing and testing of components are conducted at NASA's Michoud Assembly Facility in Louisiana and Stennis Space Center in Mississippi. SLS major components include:

- Four RS-25 rocket engines originally designed and built for the Space Shuttle, refurbished for use on SLS by Aerojet Rocketdyne.[10]
- Two five-stage solid rocket boosters built by the Northrop Grumman Corporation[11] based on the Shuttle design, with some refurbished Shuttle components
- A core stage being built by the Boeing Corporation (Boeing).
- An upper stage built by Boeing, initially the Interim Cryogenic Propulsion Stage (ICPS) and then the EUS (Block 1B and Block 2). Both use Aerojet Rocketdyne RL-10 engines.

The RS-25 engines, solid rocket booster segments, and ICPS for EM-1 were successfully delivered to NASA and have undergone qualifications testing, and they are ready for final assembly and integration upon completion of the core stage. In August 2019, NASA and Boeing announced a major development milestone for the core stage: the completed assembly of the engine section, the most complex element of the core stage, which houses the four RS-25 engines and includes the vital systems that govern delivery of propellant to those engines.[12]

NASA plans to launch EM-1 and EM-2 on an SLS Block 1 (70 mt to LEO). NASA had notionally planned to debut the Block 1B (105 mt to LEO) in 2024 on EM-3 and Block 2 (70 mt to LEO) on EM-8 in 2028;[13] however, the agency has not updated that schedule since receiving the directive to land astronauts on the Moon in 2024. The President's FY 2020 budget request did not propose funding for continued EUS development, which would be used on the Block 1B and Block 2 variants of the SLS.

Overview of the Orion Multipurpose Crew Vehicle

Under the Constellation program, NASA undertook its first major crew vehicle development effort since building the Space Shuttle in the 1970s. The NASA Authorization Act of 2010 directed the agency to continue work on a crew vehicle with minimum requirements including:[14]

- The capability to serve as the primary crew vehicle for missions beyond LEO

[10] Aerojet Rocketdyne is contracted to refurbish sixteen Shuttle RS-25 engines for the first four SLS flights; on a separate contract, the company is restarting production in 2018 in order to manufacture six new engines for a fifth.
[11] Originally contracted to Alliant Techsystems, which merged with Orbital Science Corporation to become Orbital ATK in 2015, which was purchased by the Northrop Grumman Corporation in 2018. Contract includes three flight sets of boosters and one test set.
[12] Sloss, Phillip, "Boeing Completes First NASA SLS Engine Section, Getting Ready for Final Core Stage Mate," *NASASpaceFlight*, August 25, 2019. Available at: https://www.nasaspaceflight.com/2019/08/sls-engine-section-ready-final-core-mate/
[13] IDA Science & Technology Policy Institute, "Evaluation of a Human Mission to Mars by 2033," March 2019. Available at: https://www.ida.org/-/media/feature/publications/e/ev/evaluation-of-a-human-mission-to-mars-by-2033/d-10510.ashx
[14] Title 42, U.S. Code, Section 18323, Multi-purpose crew vehicle. Available at: https://www.law.cornell.edu/uscode/text/42/18323

- The capability to conduct regular in-space operations in conjunction with payloads delivered by the SLS or other vehicles
- The capability to serve as a backup crew and cargo vehicle for the ISS
- The capacity for efficient and timely evolution

The Orion multipurpose crew vehicle comprises three primary components: the Launch Abort System (LAS), the Crew Module (CM), and the Service Module (SM). The LAS is intended to safely propel the crew module away from the SLS prior to or in the first several minutes after launch in case of any threat to the astronaut crew. The crew capsule can provide habitation and life support for up to four astronauts for up to 21 days. The service module will provide propulsion, air, water, and power to the crew module.

The Orion program is managed out of the Johnson Space Center (JSC), which reports to the ESD division at NASA Headquarters. Lockheed Martin is the prime contractor for the Orion crew spacecraft (including both the LAS and the CM). NASA and Lockheed Martin recently reached a major milestone with the successful demonstration of the LAS in-flight abort capability in the Ascent Abort test on July 2, 2019. The European Space Agency (ESA) developed and produced the European Service Module (ESM) for EM-1 and EM-2; NASA accepted the delivery of the EM-1 ESM from ESA in November 2018 and mated the CM and ESM in July 2019 to form the completed, combined system, the Crew and Service Module (CSM). NASA plans to deliver the CSM to its Plum Brook facility at the Glenn Research Center in Ohio for thermal vacuum testing in September 2019.

Overview of the Exploration Ground Systems (EGS) Program

All SLS launches will use the facilities of NASA's KSC. EGS is a development and operations program for the systems and facilities KSC will use to process and launch modern and next-generation vehicles and spacecraft, including SLS and Orion. EGS activities include modernizing computational hardware and software, developing new ground systems, and upgrading or refurbishing existing infrastructure. The EGS program is managed out of KSC, which reports to the ESD division at NASA Headquarters.

EGS software development efforts include the Space Command and Control System and Ground Flight Application Software. Key facilities of the EGS program include the Vehicle Assembly Building (VAB), the Mobile Launcher and Crawler-Transporter, and Launch Pad 39B. During final integration for launch, SLS will be assembled ("stacked") on the mobile launcher in the VAB. The Crawler-Transporter will then move the stacked SLS and mobile launcher at a top speed of one mile per hour to Launch Pad 39B, 4.2 miles away.

NASA has renovated the VAB, Launch Pad 39B, and the Crawler-Transporter-2 (CR-2) under the EGS program. Upgrades to the Mobile Launcher are underway. NASA is also beginning construction of a second mobile launcher (ML2), as directed by Congress in the FY 2018 appropriations legislation,[15] rather than upgrade the existing mobile launcher to be able to support the larger Block 1B and 2 SLS configurations. Without ML2, more extensive upgrades

[15] Pub. L. No. 115-141, "Consolidated Appropriations Act, 2018," Title II. Available at: https://www.congress.gov/bill/115th-congress/house-bill/1625

to the only SLS mobile launcher would have forced a gap between the first SLS launch (EM-1, on a Block 1) and the second (EM-2, then planned on a Block 1B) of 33 months. The President's FY 2020 budget proposal provided no additional funds for the ML2.

Safety

The 2018 Annual Report of the Aerospace Safety Advisory Panel (ASAP)[16] noted "*significant progress in many areas*" by NASA's ESD program, including full-scale structural testing; initial power-on testing, structural qualification, and parachute qualification testing for Orion; and delivery of the ESM. However, ASAP noted several remaining technical challenges and concerns, including whether the Environmental Control and Life Support System (ECLSS) will be "*fully tested, qualified, and ready to support the crew launch for EM-2;*" the ESM's "*serial propellant system design, along with several of the zero-fault-tolerant design aspects of this system;*" the potential for an Orion avionics box failure that could prevent obtaining adequate heat shield performance data in EM-1; and the "*considerable technical risk*" of validation of flight control and ground system software. More generally, the report noted that, even though the ASAP feels that "*technical risks can most directly affect safety,*" the panel observed that "*many of the risks automatically elevated to NASA Headquarters for review seem to be risks that are programmatically oriented (cost, schedule, funding) as opposed to the technical risks that require engineering design or operationally targeted solutions for mitigation.*"

More generally, the ASAP regularly notes the importance to safety and risk reduction of adequate funding profiles and a regular, predictable cadence of development and operational missions. This is consistent with the recommendations of the 2014 National Academies' *Pathways to Exploration* consensus study report,[17] which included "*funding a frequency of flights sufficiently high to ensure the maintenance of proficiency among ground personnel, mission controllers, and flight crews.*" As an example of this principle, the construction of ML2 was directed by Congress in part due to a 2017 warning by ASAP that the extended operational gap while waiting for the modifications would expose the program to significant safety risks.[18]

Budget

NASA funds the development of the Orion, SLS, and EGS programs under the Exploration Systems Development (ESD) division within the Human Exploration and Operations Mission Directorate (HEOMD) budget line. In response to the Trump Administration's directive to accelerate the first human lunar landing to 2024, the Office of Management and Budget released an amended Fiscal Year (FY) 2020 budget request in May 2019 that sought an additional $1.6 billion for NASA. That followed the President's initial FY 2020 request of $21 billion for NASA that was issued in March 2019. Of the additional $1.6 billion in the amended request, $1.375

---

[16] ASAP, "Annual Report for 2018," January 1, 2019. Available at: https://oiir.hq.nasa.gov/asap/documents/2018_ASAP_Report-TAGGED.pdf
[17] National Research Council, *Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration*, The National Academies Press, 2014. Available at: https://doi.org/10.17226/18801
[18] ASAP, "Annual Report for 2017," January 1, 2018. Available at: https://oiir.hq.nasa.gov/asap/documents/2017_ASAP_Annual_Report.pdf

billion is proposed for Deep Space Exploration Systems, including funding to "*accelerate the development of human-rated lunar lander systems*" and "*to preserve the flight schedule for the Space Launch System rocket and Orion capsule.*" Following the release of the budget amendment, NASA identified its plans for allocating $651 million of the proposed amendment for Deep Space Exploration Systems between the SLS and Orion programs.[19] The original FY 2020 budget request for the Orion, SLS, and EGS programs and NASA's plans for the amended budget are shown in the table below.

	FY 2018		FY 2019		FY 2020		
	Request	**Actual**	Request	**Enacted**	President's Budget Request	NASA Plan under Amended Request	House Appropriations
Orion	$1,186.0	**$1350.0**	$1,160.0	**$1350.0**	$1266.2	$1,406.7	$1,425.0
SLS	$1,937.8	**$2150.0**	$2,078	**$2150.0**	$1775.4	$2,285.9	$2,150.0
EGS	$460.4	**$895.0**	$428.0	**$592.8**	$400.1	$400.1	$592.8

Amounts listed are in millions of then-year dollars. Adapted from NASA FY 2020 Congressional Budget Justification,[20] NASA FY 2020 Budget Amendment Summary,[21] and NASA presentation.[22]

It should be noted that the President's original FY 2020 budget request proposed less for SLS, Orion, and EGS than was provided in the FY 2019 appropriation. Furthermore, as indicated in the above table, NASA has typically requested less than has ultimately been appropriated by Congress for Orion, SLS, and EGS development.

Cost and Schedule Performance and Challenges

Many components of the SLS, Orion, and EGS systems have reached or are near completion, though major milestones remain, and each program has already seen both cost and schedule growth from the baseline commitments NASA made in 2014 and 2015. The Government Accountability Office (GAO) has identified aspects of cost and schedule management that have affected the programs; in its most recent response to a GAO assessment, NASA emphasized that "*the issues encountered are commensurate with first-time production programs on a large scale and should not be unexpected.*"[23]

In 2014, NASA committed to EM-1 baseline costs for SLS and EGS of $7.021 billion and $1.843 billion, respectively, and a baseline schedule for launch no later than November 2018. In 2015, NASA confirmed the Orion project for a baseline cost of $6.77 billion through launch of EM-2 no later than April 2023. After the GAO found the agency unlikely to meet the November

[19] NASA presentation to NASA Advisory Council's Committee on Human Exploration and Operations, May 29, 2019. Available at: https://www.nasa.gov/sites/default/files/atoms/files/nac_budget_charts_final_updated_pfp.pdf
[20] https://www.nasa.gov/sites/default/files/atoms/files/fy_2020_congressional_justification.pdf
[21] https://www.nasa.gov/sites/default/files/atoms/files/nasa_fy_2020_budget_amendment_summary.pdf
[22] NASA presentation to NASA Advisory Council's Committee on Human Exploration and Operations, May 29, 2019. Available at: https://www.nasa.gov/sites/default/files/atoms/files/nac_budget_charts_final_updated_pfp.pdf
[23] GAO, "NASA HUMAN SPACE EXPLORATION: Persistent Delays and Cost Growth Reinforce Concerns over Management of Programs," GAO-19-377, June 2019. Available at: https://www.gao.gov/products/GAO-19-377

2018 date,[24] NASA reported an updated cost and schedule[25] to Congress in December 2017 with an EM-1 launch no later than June 2020 (19 months delay) and revised costs for SLS and EGS of $7.169 billion (2.1 percent growth) and $2.265 billion (22.9 percent growth), respectively.

However, the recent report by GAO[26] cautioned that the June 2020 launch date is now also unlikely for EM-1.[27] GAO reports that both SLS and Orion have 6-12 months of schedule risk, estimating the EM-1 launch date as late as June 2021. The Orion ESM was successfully delivered by ESA in November 2018, but integration and testing require at least 20 months after receiving the ESM, so the earliest the Orion program could be ready to support EM-1 would be July 2020, based on the ESM schedule alone.

In the same report, GAO found further cost growth for both SLS and Orion development. Additionally, the GAO stated that NASA is underreporting the extent of that cost growth. Specifically, in estimating the SLS development costs, NASA determined it would be more appropriate to shift costs for some components to future missions but did not adjust the baseline to which they were calculating growth accordingly. Therefore, as of the fourth quarter of FY 2018, NASA reported that the SLS development cost had increased by approximately $1 billion (14.7 percent), but GAO calculated that the growth was actually $1.8 billion (29.0 percent). In the case of Orion, NASA is estimating the development cost using an internal launch target date of EM-2 that is seven months earlier than the baseline schedule commitment but did not adjust the baseline cost accordingly when making the calculation of growth. Thus, NASA reports a development cost growth for Orion of $379 million (5.6 percent); GAO cautioned that it could be much larger. GAO recommended that NASA update the SLS and Orion cost calculations; NASA concurred with the recommendation for SLS cost reporting, but not with the recommendation for the Orion cost reporting.

Both the GAO and the NASA Office of Inspector General (OIG)[28] report that NASA cannot make robust estimates of the cost of future missions, in part because EGS and SLS do not have a baseline for cost and schedule beyond EM-1, and Orion does not have a baseline for cost and schedule beyond EM-2. NASA has started procuring some long-lead materials for a 2024 Artemis 3 flight of SLS and Orion under modifications to existing contracts, but new contracts have not yet been signed for either the next core stage or crew vehicle beyond EM-2.[29]

---

[24] GAO, "NASA HUMAN SPACE EXPLORATION: Delay Likely for First Exploration Mission," GAO-17-414, April 27, 2017. Available at: https://www.gao.gov/products/GAO-17-414

[25] Per Title 51, U.S. Code Section 30104, the NASA Administrator must inform the Senate Commerce, Science, and Transportation Committee and the House Science, Space, and Technology Committee when either the development cost of a program is likely to exceed the baseline estimate by 15 percent or more, or a milestone is likely to be delayed by six months or more. NASA calls this process a "replan."

[26] GAO, "NASA HUMAN SPACE EXPLORATION: Persistent Delays and Cost Growth Reinforce Concerns over Management of Programs," GAO-19-377, June 2019. Available at: https://www.gao.gov/products/GAO-19-377

[27] None of the analysis from GAO or the NASA OIG examined any potential impacts to either budget or schedule caused by the partial government shutdown in December-January of Fiscal Year 2019.

[28] NASA OIG, "NASA's Management of the Space Launch System Stages Contract," IG-19-001, October 10, 2018. Available at: https://oig.nasa.gov/docs/IG-19-001.pdf

[29] Sloss, Phillip, "NASA Starts Buying Long Lead Parts for Third Orion ESM, SLS Core Stage," *NASASpaceflight*, August 8, 2019. Available at: https://www.nasaspaceflight.com/2019/08/nasa-buying-long-lead-parts-third-orion-sls/

SLS and Robotic Exploration of Deep Space

The cargo configurations of SLS could carry robotic spacecraft conducting scientific missions, and the size and lift capabilities of the rocket could significantly reduce the travel time to interplanetary destinations. For example, appropriations legislation since FY 2017 directs NASA to launch Europa Clipper, a flagship planetary science mission to study an icy moon of Jupiter, on an SLS rocket.[30] If launched on SLS, Europa Clipper could reach its destination on a direct trajectory—requiring no planetary flybys for gravity assists—in just two years, versus six years on a commercial heavy lift rocket. NASA recently committed to a cost and schedule baseline that would have the Europa Clipper spacecraft ready for launch as early as 2023, but, in May 2019, the NASA OIG reported that an SLS is "*unlikely to be available by the congressionally mandated 2023 date, and therefore the Agency continues to maintain spacecraft capabilities to accommodate both the SLS and two commercial launch vehicles.*"[31] The OIG wrote in August 2019 that an SLS for Europa Clipper would not be available until 2025 at the earliest "*because of developmental delays and, more significantly, NASA's plans to use the first three SLS rockets produced for its Artemis lunar program.*"[32]

[30] Pub. L. No. 115-31, "Consolidated Appropriations Act, 2017," Title III. May 5, 2017. Available at: https://www.congress.gov/bill/115th-congress/house-bill/244
[31] NASA OIG, "NASA's Management of NASA's Europa Mission," IG-19-019, May 29, 2019. Available at: https://oig.nasa.gov/docs/IG-19-019.pdf
[32] NASA OIG letter dated August 27, 2019. Available at: https://oig.nasa.gov/docs/Follow-uptoMay2019AuditofEuropaMission-CongressionalLaunchVehicleMandate.pdf

Chairwoman HORN. This hearing will come to order.

Without objection, the Chair is authorized to declare recess at any time.

Good morning, everyone. Thank you all for being here. And thank you to each of our witnesses for being here. We sincerely appreciate it and are looking forward to a good hearing.

Before I continue, I do want to note for the record that we received NASA's (National Aeronautics and Space Administration's) testimony less than 24 hours in advance—late again. I'm raising this for the record because I gently raised the issue at a previous NASA hearing and after having received testimony for the next morning. And we gave sufficient notice for this hearing. It is important for us to be able to review the prepared testimony to get ourselves ready for these hearings, so I expect going forward that we will receive NASA's testimony in the 48-hour window so that we can read and review the testimony in advance of each of the hearings. So I just want to make sure we put that on the record. And I'll start with my opening statement.

As I said in the first hearing of this Subcommittee in this session, "Mars is the horizon goal and I want Americans to be the first to set foot on the red planet." It is a goal worthy of this great Nation and NASA's Space Launch System (SLS), Orion Crew Vehicle, and Exploration Ground Systems (EGS), are essential core capabilities for getting us into deep space and onward to Mars. Because I believe in moving human exploration forward beyond low-Earth orbit in a safe, sustainable, and affordable way is a goal that we all share and want to achieve.

Today, many eyes are on the Moon—a steppingstone toward Mars. The Administration seeks to send humans there by 2024, 4 years earlier than the President proposed in the initial Fiscal Year 2020 budget. Can NASA do so as part of a safe, sustainable, and affordable means of achieving this Mars goal?

At this point, there are many questions that remain to be answered:

- Why did the Administration request 16 percent less than the Fiscal Year 2019-enacted levels for SLS, Orion, and EGS in its initial request for Fiscal Year 2020 while also prioritizing deep space exploration near and on the surface of the Moon?
- Why did the Administration choose not to request funding in FY 2020 for an Exploration Upper Stage (EUS) that would give SLS more lift capability to carry cargo to deep space destinations?
- Why did NASA abruptly reassign its well-respected and longstanding head of the Human Exploration and Operations Mission Directorate at a time when NASA is approaching key milestones for SLS, Orion, and Commercial Crew, while also planning for a Gateway and human landing system, all on very tight timelines?
- Why is NASA not requiring an un-crewed demonstration of a human landing system, and is this trading sustainability for affordability in a rush to send humans to the Moon by 2024?
- Is a human landing on the Moon in 2024 even possible? And if it is possible, what is it going to take in annual funding,

management capacity, and technical capability to achieve this goal?

I'm pleased that NASA and its industry partners and the exploration system workforce have made significant strides on the SLS and Orion programs in recent months. In July, the Orion program successfully tested and demonstrated the Orion launch abort system. The SLS program is integrating the core stage with the engine section in what will be a major milestone and the beginning of a complete rocket. I'm excited because clear progress increases confidence.

However, getting to this point, as we all know, has come with major challenges: Flat funding; budget overruns; technical problems; issues with program, cost, and schedule management; and instances of poor workmanship. The road ahead—integration and testing—isn't likely to be any easier. Challenges with developing programs and new technology aren't surprising, especially when we're asking NASA to push the boundaries of innovation in projects that have never been done before. What is surprising, though, is that recommendations on how to address cost, schedule, and management problems haven't been followed.

As we work to reauthorize NASA, there are still more questions that need answers:

- What is the new, rescheduled launch readiness date for the first, un-crewed SLS and Orion integrated test flight?
- How is NASA guarding against schedule pressure given the 2024 lunar landing goal?
- What are NASA's plans for completing the Exploration Upper Stage, the SLS Block 1B variant, and the second Mobile Launch Platform that is needed to launch a Block 1B vehicle?

I ask these questions because we need to know the near-term status of SLS and Orion and how that affects our overall exploration goals.

The House will soon vote on a continuing resolution for FY 2020 for funding a relatively "clean" C.R. with no additional funding for the Moon program. What will this mean for the 2024 date? In the absence of detailed information, a plan, and an estimated budget profile for the Moon program, I can't get to a clear answer.

I believe that the Members of this Subcommittee, on both sides of the aisle, share the desire for our Nation to dream big in our goals for space exploration and scientific discovery, including the goal of sending our astronauts into deep space to explore the Moon, Mars, and other destinations. Doing so will bring our society untold benefits that we can't imagine today, just as global positioning and navigation, communications satellites, medical advancements, the miniaturized camera technology even in the cell phones that we carry around and so much more now are used in our day-to-day lives.

In closing, we need to right the ship for SLS, Orion, and EGS and set a sustainable course forward. But if we're serious about a human exploration program that ultimately leads to landing humans on Mars, we need to build in sustainability, accountability, transparency, and affordability from the start. We need to learn from our challenges in order to set up a structure and manage our future human space flight programs for success.

I look forward to our witnesses' testimony.

[The prepared statement of Chairwoman Horn follows:]

Good morning, and welcome to our witnesses. We appreciate your being here.

As I said in the first hearing of the Subcommittee this Session, "Mars is the horizon goal and I want Americans to be the first to set foot on the Red Planet." It is a goal worthy of this great nation and NASA's Space Launch System-SLS-Orion Crew Vehicle, and Exploration Ground Systems-EGS-are essential core capabilities for getting us into deep space and onward to Mars. Because I believe moving human exploration beyond low Earth orbit in a safe, sustainable, and affordable way is a goal we all share and want to achieve.

Today, many eyes are on the Moon-a stepping stone toward Mars. The Administration seeks to send humans there by 2024, four years earlier than the President proposed in the initial Fiscal Year 2020 budget request. Can NASA do so as part of a safe, sustainable, and affordable means of reaching the Mars goal?

At this point, many questions remain unanswered.

- Why did the Administration request 16 percent less than the FY 2019 enacted level for SLS, Orion and EGS in its initial request for fiscal year 2020 while also prioritizing deep space exploration near and on the surface of the Moon?
- Why did the Administration choose not to request funding in FY 2020 for an Exploration Upper Stage that would give SLS more lift-capability to carry cargo to deep space destinations?
- Why did NASA abruptly reassign its well-respected and longstanding head of the Human Exploration and Operations Mission Directorate at a time when NASA is approaching key milestones for SLS and Orion, and Commercial Crew, while also planning for a Gateway and human landing system, all on tight timelines?
- Why is NASA not requiring an uncrewed demonstration of a human landing system and is this trading "sustainability" for "affordability" in a rush to send humans to the Moon by 2024?
- Is a human landing on the Moon in 2024 even possible? And if it is possible, what is it going to take in annual funding, management capacity, and technical capability to achieve this goal?

I'm pleased that NASA, its industry partners, and the exploration systems workforce have made significant strides on the SLS and Orion programs in recent months. In July, the Orion program successfully tested and demonstrated the Orion launch abort system. The SLS program is integrating the core stage with the engine section in what will be a major milestone and the beginning of a complete rocket. I'm excited, because clear progress increases confidence.

However, getting to this point has come with major challenges: flat funding, budget overruns, technical problems, issues with program, cost, and schedule management, and instances of poor workmanship. The road ahead-integration and testing-isn't likely to be any easier.

Challenges with development programs aren't surprising, especially when we're asking NASA to push the boundaries of innovation in projects that have never been done before. What is surprising, though, is that recommendations on how to address cost, schedule, and management problems haven't been followed.

As we work to reauthorize NASA, there are still more questions that need answers.

- What is the new, rescheduled launch readiness date for the first, uncrewed SLS and Orion integrated test flight?
- How is NASA guarding against schedule pressure given the 2024 lunar landing goal?
- What are NASA's plans for completing the Exploration Upper Stage, the SLS Block 1B variant, and the second Mobile Launch Platform that is needed to launch a Block 1B vehicle?

I ask these questions because we need to know how the near-term status of SLS and Orion affects our overall exploration goals. The House will vote soon on a Continuing Resolution for FY 2020-a relatively "clean" CR with no additional funding for the Moon program. What will this mean for the 2024 date? In the absence of detailed information, a plan, and an estimated budget profile for the Moon program, I can't get to a clear answer.

I believe that Members of this Subcommittee on both sides of the aisle share the desire for this nation to dream big in our goals for space exploration and scientific discovery, including the goal of sending our astronauts into deep space to explore the Moon, Mars and other destinations. Doing so will bring our society untold benefits that we can't imagine today, just as global positioning and navigation, communications satellites, medical advancements, and the miniaturized camera technologies that are now used in our smart phones have demonstrated.

In closing, we need to right the ship for SLS, Orion, and EGS and set a sustainable course going forward. But if we're serious about a human exploration program that ultimately leads to landing humans on Mars, we need to build in sustainability, accountability, transparency, and affordability from the start. We need to learn from our challenges in order to set-up, structure, and manage our future human space flight programs for success. I look forward to our witness' testimonies.

Thank you.

Chairwoman HORN. I recognize the Ranking Member for your opening statement.

Mr. BABIN. Thank you, Madam Chair. Great to be here, and thank you, witnesses. Looking forward to your testimonies.

NASA's long-term goal, as laid out consistently in 2005, 2008, 2010, and the 2017 NASA Authorization Acts, is to explore the Moon, Mars, and beyond in steppingstone approach based on available funding.

Numerous reports over the last 50 years have all determined that we need at least a 40- to 60-ton launch vehicle, and ideally a 130-ton launch vehicle, to conduct any meaningful exploration of deep space. We also need a crew capsule that can operate for extended periods in deep space with sufficient environmental controls and life support systems and in-space propulsion capability, and the ability to withstand reentry from the Moon and from Mars. The Space Launch System, Orion Crew Vehicle, and Exploration Ground Systems are the only systems designed to operate beyond low-Earth orbit. They are the tip of the spear of our Nation's deep space exploration efforts.

SLS and Orion will enable U.S. astronauts to return to the Moon for the first time since Gene Cernan left his daughter's name in the lunar regolith in 1972. As Vice President Pence said in the inaugural meeting of the reestablished National Space Council, "We will return American astronauts to the Moon, not only to leave behind footprints and flags, but also to build the foundation that we need to send Americans on to Mars and beyond."

I wholeheartedly support the Administration's call to return to the Moon and its renewed sense of urgency. This Committee has received testimony time and time again that the Moon is the appropriate next destination for our space program. Returning to the Moon does not have to mean delaying a mission to Mars. On the contrary, it is the logical step that enables exploration of the red planet and beyond.

And while I'm excited by the promise of how strategic assets like SLS and Orion will enable America's return to the Moon, this Committee has a responsibility to conduct oversight to ensure that these programs are successful. All three exploration systems: SLS, Orion, and Ground Systems have experienced many delays and cost overruns over the years. Some of the setbacks were caused by Administrations that tried to stifle program budgets and even cancel the programs. Some of the issues were caused by unforeseen events like tornadoes and hurricanes. But many of the issues recently were caused by poor execution. As the GAO (Government Accountability Office) testimony reports, quote, "management and oversight problems are the real drivers behind program cost and schedule growth," unquote. Congress needs to understand where the program is today. What cost, schedule, and performance deliverables can the agency commit to? What is the plan going forward? How will NASA manage future issues to ensure long-term program sustainability?

As I said at the last hearing on these programs, we aren't out of the woods yet, but we can now see the edge of the forest at least. Significant progress has been made, but not as much as we had hoped. We must have that sense of urgency.

In order to meet our Nation's space exploration goals, it will take focus and discipline, continuity of effort to go forward. The Administration and Congress must not only provide leadership and direction, but we must also appropriately fund and oversee these programs. NASA must develop future exploration architectures that use the capabilities of SLS and Orion to their full potential rather than setting them up for failure.

Similarly, NASA and the contractors must execute, and failure to do so could have dire consequences for the whole program, and there will be no one else to blame. The Administration has demonstrated its renewed support. Congress consistently funds the program at healthy levels. It is time for NASA and the contractors to deliver.

And I am very thankful that our witnesses are here today to help us better understand where we are in this program, and how we plan to move forward. And I look forward to your testimony.

And thank you, Madam Chair. I yield back.

[The prepared statement of Mr. Babin follows:]

NASA's long-term goal, as laid out consistently in the 2005, 2008, 2010, and 2017 NASA Authorization Acts, is to explore the Moon, Mars, and beyond in stepping stone approach based on available funding.

Numerous reports over the last 50 years have all determined that we need at least a 40-60 ton launch vehicle, and ideally a 130 ton launch vehicle, to conduct any meaningful exploration of deep space. We also need a crew capsule that can operate for extended periods in deep space with sufficient environmental controls and life support systems and in-space propulsion capability, and the ability to withstand reentry from the Moon and Mars. The Space Launch System (SLS), Orion Crew Vehicle, and Exploration Ground Systems are the only systems designed to operate beyond low Earth orbit. They are the tip of the spear of our nation's deep space exploration efforts.

SLS and Orion will enable U.S. astronauts to return to the Moon for the first time since Gene Cernan left his daughter's name in the lunar regolith in 1972. As Vice President Pence said in the inaugural meeting of the reestablished National Space Council, "We will return American astronauts to the Moon, not only to leave behind footprints and flags, but to build the foundation we need to send Americans to Mars and beyond."

I wholeheartedly support the Administration's call to return to the Moon and renewed sense of urgency. This Committee has received testimony time and again that the Moon is the appropriate next destination for our space program. Returning to the Moon does not have to mean delaying a mission to Mars. On the contrary, it is a logical step that enables exploration of the red planet and beyond.

While I am excited by the promise of how strategic assets like SLS and Orion will enable America's to return to the Moon, this Committee has a responsibility to conduct oversight to ensure these programs are successful. All three exploration system elements - SLS, Orion, and Ground Systems - have experienced many delays and overruns over the years. Some of the setbacks were caused by Administrations that tried to stifle program budgets and even cancel the programs.

Some of the issues were caused by unforeseen events like tornadoes and hurricanes. But many of the issues recently were caused by poor execution. As the GAO's testimony reports, "...management and oversight problems are the real drivers behind program cost and schedule growth." Congress needs to understand where the program is today. What cost, schedule, and performance deliverables can the agency commit to? What is the plan going forward? How will NASA manage future issues to ensure long-term program sustainability?

As I said at the last hearing on these programs, we aren't out of the woods yet, but we can see the edge of the forest. Significant progress has been made, but not as much as we had hoped. We must have a sense of urgency.

In order to meet our nation's space exploration goals, it will take focus, discipline, and continuity of effort going forward. The Administration and Congress must not only provide leadership and direction, but we also must appropriately fund and oversee the program. NASA must develop future exploration architectures that use the capabilities of SLS and Orion to their full potential rather than setting them up for failure.

Similarly, NASA and the contractors must execute. Failure to do so could have dire consequences for the program, and there will be no one else to blame. The Administration has demonstrated its renewed support. Congress consistently funds the program at healthy levels. It is time for NASA and the contractors to deliver.

I am thankful that our witnesses are here today to help us better understand where we are at with the program, and how we plan to move forward. I look forward to your testimony.

Chairwoman HORN. Thank you, Mr. Babin.

The Chair now recognizes the Chairwoman of the Full Committee, Ms. Johnson, for an opening statement.

Chairwoman JOHNSON. Thank you very much and good morning and welcome to our witnesses and thanks to all the Subcommittee Members who are present.

I want to thank you, Chairwoman Horn and Ranking Member, for today's hearing on NASA's Space Launch System, the Orion Crew Vehicle, the Exploration Ground Systems, which are essential elements of the Nation's human exploration program.

I want to echo Chairwoman Horn's comment about the lateness of NASA's testimony. NASA was provided ample advance notice of this hearing and more than sufficient time to prepare testimony and have it reviewed by OMB (Office of Management and Budget) or whomever else looks over NASA's testimony these days. The fact that this testimony is overdue is not only frustrating, it leaves Members little opportunity to consider NASA's testimony in advance of the hearing. If NASA and the Administration can't meet simple hearing deadlines, it doesn't inspire great confidence in their ability to meet the much harder deadline of landing astronauts on the Moon by 2024.

Turning to the focus of this hearing, we are going to need SLS, Orion, and the associated ground systems if we are going to send our astronauts to the worlds beyond our own, whether it's to the Moon or Mars or other destinations. We need to be sure they are developed efficiently and are well-managed.

I certainly want this Nation to explore deep space with humans once again, and I think it is a sentiment shared by Members on both sides of the aisle. However, having recently reflected on the 50th anniversary of Apollo 11, it's clear that we need to do it right: Safely, sustainably, and affordably. That's not an easy task.

The Apollo program was aggressive and bold, but it also featured extensive testing, the efforts of hundreds of thousands of dedicated civil servants and contractors, relative budgetary stability, and an effective organizational structure led by experienced engineers and program managers. It also had the benefit of an extensive series of Mercury and Gemini precursor missions that helped mature the design and operational techniques used in the Apollo program.

As I look at the few details that are available on the Trump Administration's 2024 Moon landing initiative, the contrast with Apollo is striking and troubling. It has been 47 years since we sent astronauts beyond low-level orbit. It has been almost a decade since an American spacecraft sent astronauts into space at all. Yet the Administration's plan requires astronauts to attempt a lunar landing on only the second crewed flight beyond low-Earth orbit after what by then will have been a 50-year hiatus, with no real plans for prior crewed preparatory flights in low-Earth orbit. And based on the information available to date, that landing attempt could also be the first flight of the lunar landing and ascent vehicles and transfer vehicles. That is, the schedule doesn't appear to baseline any test flights prior to the first crewed lunar landing attempt.

That first lunar landing attempt will also be the first crewed visit to the Gateway. There will be no prior crewed visits to the Gateway to check it out before using it to initiate the lunar landing attempt. And under current plans, it looks like the Administration is proposing to have the set of three lunar landing system vehicles—vehicles that do not yet exist either in government or in the private sector—be provided for NASA's use under a fixed-price commercially provided service. That is, the government would not own them or have any significant oversight of their development. And of—all of this would have to happen by 2024.

Moreover, it has now been more than 2 months since the head of the NASA Human Exploration and Operations Directorate was removed from his position with no permanent replacement yet identified even though that position is critical to the success of NASA's Exploration and ISS (International Space Station) programs. And we have been told not to expect a cost estimate or budget plan for the President's Moon program before next year.

I could go on, but I hope that my point is clear. Rhetoric about American leadership in space and advancing the role of women in spaceflight is all well and good, but it is not a substitute for a well-planned, well-managed, well-funded, and well-executed exploration program. To date, Congress has not been given a credible basis for believing that the President's Moon 2024 program satisfies any of those criteria.

In short, if Congress is to support such a program, the Administration is going to have to do a lot more to provide such evidence.

I again want to welcome all of our witnesses, and I look forward to your testimony.

And with that, Madam Chair, I yield back.

[The prepared statement of Chairwoman Johnson follows:]

Good morning and welcome to our witnesses.

I want to thank Subcommittee Chairwoman Horn for holding today's hearing on NASA's Space Launch System, Orion crew vehicle, and Exploration Ground Systems, which are essential elements of the nation's human exploration program.

I also want to echo Chairwoman Horn's comment about the lateness of NASA's testimony. NASA was provided ample advance notice of this hearing and more than sufficient time to prepare testimony and have it reviewed by OMB and whomever else looks over NASA's testimony these days. The fact that this testimony is overdue is not only frustrating, it leaves Members little opportunity to consider NASA's testimony in advance of the hearing. If NASA and the Administration can't meet simple hearing deadlines, it doesn't inspire great confidence in their ability to meet the much harder deadline of landing astronauts on the Moon by 2024.

Turning to the focus of this hearing, we are going to need SLS, Orion, and the associated ground systems if we are going to send our astronauts to worlds beyond our own, whether it's the Moon, Mars or other destinations. We need to be sure they are developed efficiently and are well managed. I certainly want this nation to explore deep space with humans once again, and I think that is a sentiment shared by Members on both sides of the aisle. However, having recently reflected on the 50th anniversary of Apollo 11, it's clear that we need to do it right-safely, sustainably, and affordably.

That's not an easy task. The Apollo program was aggressive and bold, but it also featured extensive testing, the efforts of hundreds of thousands of dedicated civil servants and contractors, relative budgetary stability, and an effective organizational structure led by experienced engineers and program managers. It also had the benefit of an extensive series of Mercury and Gemini precursor missions that helped mature the design and operational techniques used in the Apollo program. As I look at the few details that are available on the Trump Administration's 2024 Moon landing initiative, the contrast with Apollo is striking and troubling.

It has been 47 years since we sent astronauts beyond low Earth orbit. It has been almost a decade since an American spacecraft sent astronauts into space at all. Yet the Administration's plan requires our astronauts to attempt a lunar landing on only the second crewed flight beyond low Earth orbit after what by then will have been a 50-year hiatus, with no real plans for prior crewed preparatory flights in low Earth orbit. And based on the information available to date, that landing attempt could also be the first flight of the lunar landing and ascent vehicles and transfer vehicle. That is, the schedule doesn't appear to baseline any test flights prior to the first crewed lunar landing attempt. That first lunar landing attempt will also be the first crewed visit to the Gateway. There will be no prior crewed visits to the Gateway to check it out before using it to initiate the lunar landing attempt.

And under current plans, it looks like the Administration is proposing to have the set of three lunar landing system vehicles-vehicles that do not yet exist either in government or in the private sector-be provided for NASA's use under a fixed price commercially-provided service. That is, the government would not own them or have any significant oversight of their development. And all of this would have to happen by 2024.

Moreover, it has now been more than two months since the head of the NASA Human Exploration and Operations Directorate was removed from his position, with no permanent replacement yet identified-even though that position is critical to the success of NASA's Exploration and ISS programs. And we have been told not to expect a cost estimate or budget plan for the President's Moon program before next year.

I could go on, but I hope my point is clear. Rhetoric about American leadership in space and advancing the role of women in spaceflight is all well and good, but it is not a substitute for a well planned, well managed, well funded, and well executed exploration program. To date, Congress has not been given a credible basis for believing that the President' Moon 2024 program satisfies any of those criteria. In short, if Congress is to support such a program, the Administration is going to have to do a lot more to provide such evidence.

I again want to welcome our witnesses, and I look forward to your testimony. With that, I yield back the balance of my time.

Chairwoman HORN. Thank you, Chairwoman Johnson.

The Chair now recognizes the Ranking Member of the full Committee and fellow Oklahoman, Mr. Lucas, for an opening statement.

Mr. LUCAS. Thank you, Madam Chair.

When we celebrated the 50th anniversary of the Moon landing this summer, it was a great reminder of the great things that we can achieve with perseverance, technical excellence, and a pioneering spirit. The Trump Administration has harnessed this spirit of discovery and focused our human space exploration efforts. By staying the course on programs like Space Launch System, Orion, Exploration Ground Systems, the Administration is ensuring that our national goals to explore the Moon, Mars, and beyond will be achieved. This support is backed up by this Administration with its robust funding request.

Year after year, the Trump Administration has proposed increased funding for NASA Exploration Systems, only to have Congress appropriate even more than the Administration requested. This year, the Administration took the extraordinary step of amending its budget by requesting an additional $1.6 billion to accelerate our return to the Moon by 2024. This will serve as a down payment on the systems necessary to enable this goal. The primary elements are already well under development.

The Space Launch System, Orion Crew Capsule, and the Exploration Ground Systems will serve as the foundation for future exploration of the Moon and Mars. Congress has also provided consistent funding for the advanced capacities like the Exploration Upper Stage and additional Mobile Launch Platforms. These will accelerate the development of a 130-ton launch vehicle, which is optimum for deep space exploration.

This steady funding is a blessing and, yes, a curse. Too often programs become complacent when funding is taken for granted. Congress and NASA need to be good stewards of taxpayer dollars and ensure these programs stay focused, on schedule, and within cost.

But adequately funding SLS, Orion, and ground systems are only part of what is needed for a lunar exploration. NASA also needs to develop a human lander and associated support systems. NASA's budget request already plants the seeds for technologies that will be necessary, but it is scheduled to deliver a more detailed plan with their Fiscal Year 2021 budget proposal. I look forward to reviewing that upcoming request.

Nearly 30 years ago, western Oklahoma's favorite son, General Tom Stafford, delivered a report entitled, "America at the Threshold." My friends, we are once again at the threshold, and our actions will determine our future space leadership. But unlike 30 years ago, we have hardware ready to be delivered, an Administration with a sense of urgency, and a Congress that I believe is onboard.

We also have new challenges to our leadership in space. Last year, China conducted the most launches in the world. They have already launched crewed missions and a temporary space station. They landed a rover on the far side of the Moon—a first for humanity—and plan to land a crew on the Moon in the coming years. They are also seeking international partnerships. We have a responsibility to ensure that America remains the world leader in space exploration, that humanity's push into deep space is led by freedom and liberty rather than communism.

As our Nation once again stood at the threshold of deep space, it is up to Congress to fund the program appropriately. It is also up to NASA to develop a plan that maximizes the down payments made on SLS, Orion, and ground systems. We cannot afford to cede our leadership in space exploration. I trust, I believe, I have confidence that we can all work together to achieve our shared goals.

I yield back, Madam Chair.

[The prepared statement of Mr. Lucas follows:]

When we celebrated the 50th anniversary of the Moon landing this summer, it was a great reminder of the great things we can achieve with perseverance, technical excellence, and a pioneering spirit. The Trump Administration has harnessed this spirit of discovery and focused our human space exploration efforts. By staying the course on programs like the Space Launch System, Orion, and Exploration

Ground Systems, the Administration is ensuring that our national goals to explore the Moon, Mars, and beyond will be achieved. This support is backed up by this Administration with its robust funding requests.

Year after year, the Trump Administration has proposed increased funding for NASA Exploration Systems, only to have Congress appropriate even more than the Administration requested. This year the Administration took the extraordinary step of amending their budget by requesting an additional $1.6 billion to accelerate our return to the Moon by 2024. This will serve as a down payment on the systems necessary to enable this goal. The primary elements are already well under development.

The Space Launch System, the Orion Crew Capsule, and the Exploration Ground Systems will serve as the foundation for the future exploration of the Moon and Mars. Congress has also provided consistent funding for advanced capabilities like the Exploration Upper Stage and additional Mobile Launch Platforms. These will accelerate the development of a 130 ton launch vehicle, which is optimum for deep space exploration.

But this steady funding is a blessing and curse. Too often programs become complacent when funding is taken for granted. Congress and NASA need to be good stewards of taxpayer dollars and ensure these programs stay focused, on schedule, and within cost.

But adequately funding SLS, Orion, and ground systems are only part of what is needed for Lunar exploration. NASA also needs to develop a Human Lander and associated support systems. NASA's budget request already plants the seeds for technologies that will be necessary, but it is scheduled to deliver a more detailed plan with their fiscal year 2021 budget proposal. I look forward to reviewing the upcoming request.

Nearly 30 years ago, western Oklahoma's favorite son, Gen. Tom Stafford, delivered a report titled "America at the Threshold." Folks, we are once again at the threshold and our actions now will determine our future leadership in space. But unlike 30 years ago, we have hardware ready to be delivered, an Administration with a sense of urgency, and a Congress that is onboard.

We also have new challenges to our leadership in space. Last year China conducted the most launches in the world. They have already launched crewed missions and a temporary space station. They landed a rover on the far side of the Moon - a first for humanity - and plan to land a crew on the Moon in the coming years. They are also seeking international partnerships. We have a responsibility to ensure that America remains the world leader in space exploration, and that humanity's push into deep space is led by freedom and liberty rather than communism.

As our nation once again stand at the "threshold" of deep space, it is up to Congress to fund the program appropriately. It is also up to NASA to develop a plan that maximizes the down payments made on SLS, Orion, and Ground Systems. We cannot afford to cede our leadership in space exploration. I trust we can all work together to achieve our shared goals.

Chairwoman HORN. Thank you, Ranking Member Lucas.

And at this time I would like to introduce our witnesses. Our first witness today is Mr. Kenneth Bowersox, acting Associate Administrator for NASA's Human Exploration and Operations Mission Directorate where he provides the agency with leadership and management of NASA's human exploration space operations in and beyond low-Earth orbit. Mr. Bowersox was selected to the Astronaut Corps in 1987 and logged over 200 days in space. He went on to serve as a Director of Johnson Space Center's Flight Crew Operations Directorate, and previously, he was a member of the Standing Review Boards for the ISS, Space Shuttle, and the Constellation Program and was Vice President of Astronaut Safety and Mission Assurance at Space Exploration Technologies. Mr. Bowersox also served as the Chair of NASA's Advisory Council's Human Exploration and Operations Committee.

Mr. Bowersox received a degree in aerospace engineering from the United States Naval Academy and holds the rank of Captain in the United States Navy. Mr. Bowersox was also inducted into the Astronaut Hall of Fame in 2010. Welcome, Mr. Bowersox. We're glad that you're with us today.

Our second witness is Ms. Cristina Chaplain. Ms. Chaplain serves currently as a Director in the Contracting and National Security Acquisitions Team at the U.S. Government Accountability Office, the GAO. She has responsibility for GAO assessments of NASA, military space programs, and the Missile Defense Agency. She has recently led reviews on the Space Launch System, the Orion Crew Capsule, the James Webb Telescope, Commercial Cargo and Crew Systems, the Global Positioning System, Cyber Protection for Weapons, and Space Leadership. Ms. Chaplain has been with the GAO for 28 years, and prior to her current position, she worked with GAO's Financial Management and Information Technology Teams.

She received a bachelor's degree magna cum laude in international relations from Boston University and a master's degree in journalism from Columbia University. Welcome, Ms. Chaplain.

Our final and third witness today is Mr. Doug Cooke, an aerospace consultant with over 46 years' experience in human spaceflight programs. Mr. Cooke provides expertise on company and program strategies, program management, space policy, proposal development, strategic planning, and technical matters. Mr. Cooke previously served as the Associate Administrator for Exploration Systems Mission Directorate at NASA. While at NASA, Mr. Cooke was responsible for leading efforts to adopt the current vehicle designs for SLS and Orion. Mr. Cooke was also the Deputy Director of Exploration Systems Mission Directorate and previously spent over 30 years at Johnson Space Center in a variety of management and engineering positions.

He received a bachelor's degree summa cum laude in aerospace engineering from Texas A&M University. Welcome, Mr. Cooke.

As our witnesses, you should all know that you'll each have 5 minutes for your spoken testimony. Your written testimony will be included in the record for the hearing. When you've completed your spoken testimony, we will begin with questions, and each Member will then have 5 minutes to question the panel. And we will start today with Mr. Bowersox.

TESTIMONY OF KENNETH BOWERSOX, ASSOCIATE ADMINISTRATOR (ACTING), HUMAN EXPLORATION AND OPERATIONS, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. BOWERSOX. Good morning. It's great to be here with you today representing the men and women who serve in NASA's Human Exploration and Operations Mission Directorate. It's an honor for me to serve as the acting Associate Administrator for our directorate where our team works every day to move humanity's presence out into the solar system and gathers knowledge that makes lives better here on Earth.

The main topics of the hearing today are exploration systems development programs: The Orion spacecraft, the Space Launch System, and the Exploration Ground Systems required to prepare and launch the SLS with Orion.

Since I joined NASA as the Deputy Associate Administrator for Human Exploration and Operations in February of this year, I've been steadily impressed by the progress in all three of these programs. The first core stage of the Space Launch System is within months of completion at the Michoud Assembly Facility in Louisiana. The Orion vehicle for the first un-crewed flight of Orion around the Moon is at Kennedy Space Center perched on top of its European-built Service Module and just about ready to be shipped for testing to the Plum Brook Station vacuum facility in Cleveland. And the Exploration Ground Systems in Florida are undergoing some of their final tests in preparation for stacking of the solid rocket boosters, core stage, interim cryogenic propulsion stage, the Orion spacecraft, and its launch abort system for the first Artemis mission.

During the design, development, test, and assembly of all the parts I just mentioned, the programs have had their share of issues. Some of the issues were first-time build issues, some of the issues were due to changes in production processes, and some were issues we could have predicted. Many of those issues added time and cost under the effort to build the systems.

Despite these difficulties, the team has persisted, and we're getting closer every day to the launching of Artemis 1. While it's still early to declare a precise date of when we'll attempt to launch the first Artemis mission, my team and I are intent on maintaining the proper balance among holding schedule, understanding the cost, and learning what we need to be sure our exploration systems are ready for the crews of subsequent Artemis missions to fly to the Moon, return to Earth, and share their stories with the rest of us.

This year, we celebrated the 50th anniversary of the first landing of humans on the Moon. It's thrilling to know that we're so close to sending humans to the Moon again and that all of us here are part of that effort. I look forward to answering your questions today and sharing more about our development of SLS, Orion, and the ground systems for deep space exploration.

[The prepared statement of Mr. Bowersox follows:]

HOLD FOR RELEASE
UNTIL PRESENTED
BY WITNESS
Sept. 18, 2019

Statement of
Kenneth Bowersox
Acting Associate Administrator for Human Exploration and Operations
National Aeronautics and Space Administration

before the

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

Chairwoman Horn, Ranking Member Babin, and Members of the Subcommittee, thank you for the opportunity to appear before you today to discuss NASA's progress on our Exploration Systems Development (ESD) programs. NASA is charged with landing American astronauts near the South Pole of the Moon by the year 2024 and importantly, doing so in way to drive ourselves toward a more sustainable exploration enterprise. NASA is committed to this challenge. To meet the 2024 objectives, we continue to accelerate development of the systems required to ensure initial success including the Space Launch System (SLS) heavy lift rocket, the Orion crew vehicle, ground systems at Kennedy Space Center (KSC), the lunar Gateway spacecraft, and commercial human lander systems for transiting humans from the Gateway to the lunar surface. To achieve long-term sustainability of the enterprise, we have focused on reducing costs and incentivizing more innovation through different acquisition models to increase competition and partnerships, planning our exploration architecture to utilize advances in the commercial marketplace, and refocusing investment toward technologies that will reduce costs and increase capabilities. Each of these aspects is an integral element in NASA's plans for a sustainable exploration architecture. Now, we are engaged in the safe and rapid acceleration of these plans.

NASA has adopted the name "Artemis" after Apollo's twin sister for the Agency's lunar exploration program and is part of NASA's broader Moon to Mars exploration approach. Through the Artemis program, we will see the first woman and next man step foot on the Moon by 2024, and establish a sustainable architecture with our commercial and international partners on the Moon by 2028. NASA's plans call for one SLS, Orion, and Exploration Ground Systems (EGS) flight per year after Artemis III. The actual cadence of missions will be defined based on mission needs, available resources, and operational costs. Reducing production and operations costs will be critical for enabling an ambitious exploration program. The Moon will also be a proving ground where we will demonstrate technologies and take what we learn on the Moon and enable the next giant leap of human exploration of Mars.

NASA is pressing forward toward the early Artemis missions. Artemis I is an uncrewed test flight of SLS and Orion as an integrated system. This will be followed by Artemis II, a mission that will bring a crew around the Moon aboard SLS and Orion. In 2024, Artemis III will send the first crew to the Gateway in lunar orbit where the crew will transition to a commercial human landing system for transport to and from the lunar surface.

The fiscal year 2020 Presidential budget amendment requests an increase of $1.6 billion above the original request of $21 billion in funding for NASA. This budget amendment is the down payment required to get us out of the gate to achieve the bold goal of landing American astronauts on the Moon's

South Pole by 2024. We would appreciate your immediate help and bipartisan support. Together we will invest in America's future, inspire the Artemis generation in science, technology, engineering, and mathematics (STEM) careers, create good paying American jobs, advance science, and lead our commercial and international partners as we move forward with the first woman and next man on the Moon in 2024, a sustainable lunar architecture by 2028, and on to Mars.

Space Launch System

When it launches for the first time, the SLS will be the most powerful rocket in the world and a launch vehicle that supports a new era of exploration beyond Earth's orbit into deep space. Together SLS and Orion are a backbone of the Artemis program. SLS will launch astronauts in the Orion spacecraft on the Artemis missions to the vicinity of the Moon and the Gateway on their way to the surface of the Moon.

SLS capabilities are planned to evolve using a block upgrade approach. SLS Block 1 will have the capability to carry over 70 metric tons to low-Earth orbit (LEO) and nearly 30 metric tons to orbit around the Moon. NASA is focused on the successful completion of the Artemis I non-crewed test flight, the Artemis II first crewed test flight, and the Artemis III mission in 2024 that will enable the return to the Moon. This represents a step-by-step approach to developing the initial SLS capability. Eventually, NASA will follow on with development of the Block 1B capability.

The next evolution of the SLS, Block 1B, incorporates a new upper stage, the Exploration Upper Stage (EUS), now under development, along with updates to associated cargo adaptors. The SLS Block 1B configuration enables co-manifested payloads, increases cargo capability, and enables improved operational flexibility. While upgrading the SLS to the Block 1B configuration remains an important future capability, recent performance issues and delays in SLS core stage manufacturing and design updates related to the Exploration Upper Stage requirements require that NASA concentrate all available resources in the near term on the successful completion of Artemis I, II and III, and supporting a reliable annual SLS and Orion flight cadence thereafter. As a result, we have proposed to defer SLS Block 1B development efforts to later exploration missions. Spending to date on Block 1B (which includes EUS, related flight hardware such as the upper stage adapter, related ground processing capability including the Vehicle Assembly Building (VAB) platforms, and Mobile Launcher (ML)-2) has been consistent with legislative direction. The development and manufacturing of the first EUS, based on appropriations to date, is included in the existing SLS core stages contract. Future follow-on procurement for EUS production beyond the current contract, if directed by appropriations, would follow Government procurement practices with respect to consideration of competition.

SLS leverages over a half-century of experience with launch vehicles, including Saturn and Space Shuttle, along with advancements in technology since that time, including model-based engineering, additive manufacturing, high-fidelity computational fluid dynamics capabilities, new composite materials and production techniques, and large-scale self-reaction friction stir welding. Initial flight units use components already procured during the Space Shuttle, such as RS-25 engines and boosters. More efficient methods are under development for manufacturing these components, including new NASA investment in expendable RS-25 engines for the SLS Core Stage with the goal of achieving a lower per-unit cost than the original reusable RS-25s used as the Space Shuttle Main Engines. NASA continues to identify affordability strategies for missions beyond Artemis II. Reducing overall costs of the systems will be critical to achieving a successful and sustainable exploration capability.

During FY 2019, SLS continued to progress towards Artemis I while concurrently building flight hardware for Artemis II:

- Artemis I launch vehicle stage adapter will complete assembly and check out and will ship to KSC in Florida in preparation for integration. The adapter serves as the interface between the SLS Core Stage and the Interim Cryogenic Propulsion Stage (ICPS), the latter of which has already been delivered to KSC.
- In August 2019, at the Michoud Assembly Facility (MAF), we completed work on the engine section, the most challenging part of the SLS rocket, for Artemis I. The engine section is now ready to be integrated with the core stage.
- The four completed RS-25 flight engines are at MAF ready for integration into the Core Stage for Artemis I this fall.
- The Artemis I Core Stage components including RS-25 engines, the engine section, hydrogen tank, inter-tank, and oxygen tank are more than 80 percent complete. Horizontal mating of the engine section and RS-25 installation will begin in September 2019.
- Once both the engine section and RS-25 engines are integrated with the Core Stage for Artemis I, the rocket will be shipped from MAF in New Orleans, LA to Stennis Space Center (SSC) in Bay St. Louis, MS for Green Run testing, scheduled for mid-December of this year.
- Flight software and related avionic components continued testing in the software integration laboratory at Marshall Space Flight Center.
- All of the Artemis I booster components including aft skirt assemblies and forward assemblies are complete and will be delivered to KSC.
- SLS is making strides towards finishing Artemis II flight components including completed Core Stage solid rocket booster segments and significant progress on Core Stage-2, ICPS-2, and other elements.
- Work continued on developing the new RS-25 engines for future missions, achieving a 33 percent cost reduction with innovative and advanced manufacturing methods.

The Artemis I flight will be preceded by a Green Run test campaign scheduled for FY 2020. Planning dates for Green Run test execution are under review. The Green Run test campaign consists of a number of critical engineering tests, including a modal structural test and a cryogenic commodity loading and unloading test, followed by a test fire. For the test fire the liquid Core Stage will be loaded with liquid hydrogen fuel and liquid oxygen oxidizer in the B2 test stand at SSC and all four RS-25 engines will be fired to demonstrate the Core Stage performance prior to launch day. Upon the successful completion of the Green Run test campaign, the Core Stage will ship to KSC and complete vehicle certification.

When all Artemis I SLS hardware is delivered to KSC, the SLS team will effectively hand off all the launch components to the Exploration Ground Systems (EGS) team in Florida and the SLS program team focus will shift to Artemis II and III production for those flights. Fabrication and testing of elements of Artemis II will continue, to include the Core Stage, shipment of the solid rocket booster components, and additional flight elements. Additionally, the SLS team will continue efforts to restart RS-25 engine manufacturing to support Artemis IV+ missions.

Orion

NASA's Orion spacecraft builds upon more than 50 years of spaceflight research and development. It is uniquely designed to carry astronaut crews to deep space, provide emergency abort capability, sustain crew during space travel, and provide safe reentry at the high-Earth return velocities typically needed to come home from missions beyond low Earth orbit. Orion is capable of supporting a crew of four astronauts for periods of up to 21 days. It is designed to provide communications, navigation, power, and propulsion to carry people and cargo in the harsh environment of deep space and, with a planned mission kit, dock with the Gateway. Through modification and with the support of other new deep space elements, most of the Orion systems could be capable of operations in deep space for periods of time up to 1,000 days. The Orion will also be able to provide key initial life-support and abort capabilities to and from Gateway. Additionally, the Orion systems are designed to operate in a contingency mode to augment life support systems in other space transport systems.

Orion's Crew Module (CM), Spacecraft Adapter (SA), and Launch Abort System (LAS) incorporate numerous technology advancements and innovations. Orion's LAS can activate within milliseconds to carry the crew out of harm's way and position the module for a safe landing. The spacecraft's propulsion, thermal protection, avionics, and life support systems will enable extended duration missions beyond Earth orbit and into deep space. Its modular design will be capable of integrating additional new technical innovations as they become available.

The European Space Agency (ESA) is partnering with NASA to provide the European Service Module (ESM) for Orion. ESA is providing the ESMs to partly offset its International Space Station (ISS) financial obligations. The ESM will provide the Orion spacecraft with propulsion, electrical power, water and thermal control, and maintains the oxygen and nitrogen atmosphere for the crew.

The Orion Program made progress during FY 2019 on both Artemis I and II:

- The Orion Program conducted Propulsion Qualification Module (PQM) firings with active control of the pressurization system on the ESM. This includes the recent successful completion of the most stressful test case, called an Abort to Orbit at White Sands Test Facility near Las Cruces, NM.
- Following the functional tests, the ESM was mated with the Crew Module Adaptor (CMA) to complete the Service Module (SM) assembly. The completed Service Module was joined to the Crew Module, resulting in the combined Crew and Service Module (CSM) earlier this year. This work was performed at KSC and marked the first time all three major elements were integrated.
- The Orion program will ship the integrated Artemis I CSM to Plum Brook Station in Sandusky, OH, for thermal vacuum and electromagnetic interference testing which is a crucial step towards launch readiness. Once completed, the mated CSM will be returned to KSC for final launch processing.
- Continuing the manufacturing efforts for Artemis II, the program completed the Crew Module primary structure and is on track to complete the CMA primary structure at the Operations and Checkout (O&C) Facility at KSC.
- ESM-2 integration has begun in the Bremen, Germany clean room. Long-lead activities, such as welding of high-pressure valves and engine manufacturing, are underway.
- The Ascent Abort-2 test, which successfully demonstrated the ability to safely separate the Crew Module from the SLS during an ascent abort scenario, was carried out at Cape Canaveral from Launch Complex 46 on July 2, 2019.

In preparation for Artemis I, Orion will complete the Orion Structural Test Article (STA) configuration test in Denver, CO, and then ship it to Langley Research Center (LaRC) in Virginia for subsequent water impact testing. This is the last action in the series of tests that will complete the test campaign on the full-scale Orion STA. These tests are conducted to ensure the space-bound vehicle is ready to withstand the pressure and loads it will endure during launch, flight and landing. NASA will also stack and integrate the LAS in the LAS Facility and mate it to the CSM for Artemis I at KSC. After the mating, it will be delivered to the EGS team at KSC for final preparation and stacking in the VAB.

In preparations for Artemis II, Orion will finish outfitting the CM Pressure Vessel at KSC's O&C building. From FY 2020 through early FY 2021, the Orion program will install the Environmental

Control and Life Support Systems (ECLSS), the core avionics that provide overall spacecraft command and control, and the heatshield, which protects the vehicle and crew from the extreme temperatures of re-entry. Once installed, Orion will conduct a series of power-on, leak, functional, and proof pressure tests to ensure the health of the CM. In addition, the production of the Artemis II CMA will be completed. To prepare for mating to the ESM-2, the CMA will undergo proof pressure and leak tests followed by subsystem installations, harness testing, and Developmental Flight Instrumentation testing. ESA will complete manufacturing of ESM-2 and deliver it to the KSC O&C facility. Once the ESM-2 is delivered and functional tests are performed, it will be mated to the CMA. After mating, the Artemis II ESM will undergo functional, pressure and leak tests in preparation for integration with the CM-2 planned for crewed flight.

The Orion Program has initiated long lead material purchases for future Artemis missions, which will enable the program to meet an annual flight rate to support lunar exploration. In addition, the Orion Program will initiate production activities in FY 2020 for Artemis III, targeted to transport the crew for landing on the Moon in 2024, and will begin the production process to support annual exploration flights as planned in the Agency Moon to Mars enterprise. These missions represent United States commitment to – and a core piece of NASA's infrastructure for – exploration. Essential to building a sustainable exploration strategy will be finalizing development and reducing production and operation costs.

Exploration Ground Systems

The EGS team is preparing KSC to process and launch the SLS rocket and Orion spacecraft on Artemis missions. To achieve this transformation, NASA is developing new ground systems while refurbishing and upgrading infrastructure and facilities to meet tomorrow's demands, including those of the Artemis Program. This modernization effort is designed to maintain maximum flexibility in order to also accommodate a multitude of other potential Government and commercial space customers. Drawing on five decades of excellence in spacecraft processing and launch, KSC continues to work toward serving as a multi-user spaceport, as was envisioned post-Space Shuttle retirement.

During FY 2019, EGS has made significant progress:

- The program performed multiple successful launch pad water deluge tests using the Ignition Overpressure Protection and Sound Suppression system at Launch Pad 39B.
- In June, the Mobile Launcher, atop Crawler-Transporter 2, made its final solo trek from the Vehicle Assembly Building (VAB) to Pad 39B at KSC. The Mobile Launcher will remain at the pad over the summer, undergoing final testing and checkouts.
- NASA conducted several umbilical tests on the Mobile Launcher, including the first high speed retraction test on the Orion Service Module Umbilical (OSMU) that verified umbilical arm alignment, rotation speed, and latch back systems; a drop test of the Tail Service Mast Umbilicals (TSMU) to ensure that the umbilicals will disconnect before launch of the SLS; and a swing test of the Core Stage Inter-tank Umbilical (CSITU) on the Mobile Launcher.
- EGS engineers conducted Underway Recovery Test-7 (URT-7) off the coast of San Diego, CA, using a mock Orion Spacecraft capsule. These tests verify and validate procedures and hardware used to recover the Orion spacecraft after it splashes down in the Pacific Ocean following deep space exploration missions.
- EGS began construction for a new liquid hydrogen sphere for Launch Complex 39B at KSC. The storage facility will hold 1.25 million gallons of the propellant.
- The ESM for Artemis I arrived at KSC in November 2018 and underwent a host of tests and integration work before being connected to the Orion crew module.

- EGS continued ground systems development efforts, including efforts for Mobile Launcher structural modifications, installation of ground support equipment necessary to service the rocket and spacecraft, Vehicle Assembly Building High Bay platform work in high bays 3 and 4 necessary to access the over 30-story-tall rocket and spacecraft, and completion of environmental control system upgrades necessary to maintain proper working environment in the massive facility.
- EGS conducted the first formal terminal countdown simulation inside Firing Room 1 in the Launch Control Center at NASA's Kennedy Space Center.
- Consistent with provisions in the FY 2018 Consolidated Appropriations Act (P.L. 115-141), as well as the NASA Administrative Provision in P.L. 115-141 pertaining to the Agency's Operating Plan, NASA awarded a contract in June 2019 to start building the second Mobile Launcher platform. NASA does not have plans to utilize the second Mobile Launcher in the near term, and a final Block 1B design has not been set. NASA is deferring these activities until needed but allowing core design and construction of the platform to continue while awaiting a decision on the upper stage configuration for future missions.

In FY 2020, the EGS Program will complete software development efforts and Multi-Element Verification and Validation of the ground systems to support timely Artemis I rocket and spacecraft processing when the flight elements arrive in CY 2020. Spacecraft processing operations for Orion will take place at the Multi-purpose Payload Processing Facility, followed by SLS flight hardware assembly, SLS/Orion integration, and integrated testing at the VAB to support Artemis I. The program will complete URT 8 and 9 to ensure safe recovery of the Orion crew module after the Artemis I mission. EGS will complete ground processing operations in support of an Artemis I integrated launch.

In addition, the EGS Program will continue ground systems development efforts in support of future mission requirements, including the first crewed flight on Artemis II. This includes modifications to the pad and VAB Environmental Control System, upgrades to the Converter Compressor Facility, modifications to the Mobile Launcher to support crew missions, as well as continuation of Liquid Hydrogen Sphere Construction activities at launch pad 39B.

Artemis I

Artemis I will be the first integrated test of SLS, Orion, and EGS. The first in a series of increasingly complex missions, Artemis I will be an uncrewed flight test that will provide a foundation for human deep space exploration and demonstrate our commitment and capability to extend human existence to the Moon and beyond. During this flight, the spacecraft will launch on SLS and travel 280,000 miles from Earth, or some 40,000 miles past the far side of the Moon over the course of about a three-week mission before returning to Earth. Orion will stay in space longer than any ship for astronauts has done without docking to a space station and return home faster and hotter than ever before.

The outbound trip to the Moon will take several days, during which time engineers will evaluate the spacecraft's power, propulsion, cooling, communication and navigation systems and, as needed, correct its trajectory. Orion will fly about 62 miles (100 km) above the surface of the Moon and then use the Moon's gravitational force to propel Orion into a distant retrograde orbit, rotating opposite the direction the Moon orbits the Earth, some 40,000 miles (70,000 km) from the Moon. The spacecraft will stay in that orbit for approximately one week to collect data and allow mission controllers to assess the performance of the spacecraft.

For its return trip to Earth, Orion will do another close lunar flyby that takes the spacecraft within about 60 miles of the Moon's surface. The spacecraft will then use another precisely timed engine firing of the

ESM in conjunction with the Moon's gravity to accelerate back toward Earth. This precision maneuver will set the spacecraft on its trajectory back toward Earth to enter our planet's atmosphere traveling at 25,000 mph (11 kilometers per second), producing temperatures of approximately 5,000 degrees Fahrenheit (2,760 degrees Celsius) – faster and hotter than Orion experienced during its 2014 flight test – proving the heatshield design is ready to carry astronauts on the next flight test. After about three weeks and a total distance traveled exceeding 1.3 million miles, the mission will end as the spacecraft makes a precision landing in the Pacific Ocean within eyesight of the recovery ship off the coast of California. Following splashdown, Orion will remain powered for a period of time as divers from the U.S. Navy and operations teams from NASA's EGS team approach in small boats from the waiting recovery ship to perform an initial safety inspection. Orion will then power down to support retrieval of the capsule for post-flight engineering assessment.

Schedule performance by the SLS and Orion Programs is critical to achieving a human return to the Moon by 2024. The preponderance of SLS, Orion, and EGS development and production work is focused on Artemis I, and work is underway to prepare for the first flight of crew on Artemis II. While progress on these programs has been substantial, NASA, its contractors, and international partners have faced challenges with first-time design, assembly, and test. NASA has been working to address these development issues. Earlier this year, the Human Exploration and Operations Mission Directorate (HEOMD) completed an assessment of alternate approaches for hardware processing and facilities utilization for key components with the goal of maintaining an early as possible Artemis I launch date. The NASA Office of the Chief Financial Officer performed a schedule risk assessment of the Artemis I launch date, including the integrated schedule and associated risk factors ahead of Artemis I. NASA plans to establish a new launch date for Artemis I, after replacements are officially named for the previous HEOMD Associate Administrator and ESD Deputy Associate Administrator.

Artemis II

NASA is also moving forward on Artemis II, making progress on the SLS and Orion vehicles that will be used for that mission. Astronauts on their first flight aboard NASA's Orion spacecraft will travel farther into the solar system than humanity has ever traveled before. Their mission will confirm all of the spacecraft's systems operate as designed in the actual environment of deep space with a flight crew aboard. NASA's first Artemis mission with astronauts will mark a significant step forward on NASA's plans to return humans to the Moon for long-term exploration and future missions to worlds beyond, including Mars. The plan for the Artemis II flight is built around a profile called a hybrid free return trajectory. Orion will perform multiple maneuvers to initially raise its orbit around Earth and eventually place the crew on a free return trajectory from the Moon.

After launch, the spacecraft and upper stage of the SLS rocket will first orbit Earth twice to allow enough time for the team to assess the spacecraft's performance, including key life support systems, before committing to proceed with flight around the Moon. Orion will reach a circular orbit at an altitude of 100 nautical miles and last 90 minutes. Following the first orbit, the rocket's ICPS will perform an orbital raise, which will place Orion into a highly elliptical orbit around our planet. This is called the partial translunar injection. This second, larger orbit will take approximately 42 hours with Orion flying in an ellipse between 190 and 60,000 nautical miles above Earth. Once the integrated vehicle completes these two orbits, the ICPS will separate from Orion and the crew will do a unique test of the spacecraft's critical systems. They will gather and evaluate engineering data from the nearly two-day-long Earth orbit before using Orion's SM engine to complete a second and final propulsion move called the translunar injection (TLI) burn. This second burn will put Orion on a path toward the Moon. The TLI will send crew some 3,000 nautical miles past the far side of the Moon where they will ultimately execute a figure-eight-shaped orbit before Orion returns to Earth. Instead of requiring propulsion on the return, the spacecraft will purposefully use the Moon's gravitational pull like a slingshot to bring Orion home, which is the free return portion of the trajectory. Crew will fly thousands of miles beyond the Moon, which is an average of 230,000 miles from the Earth, setting a new record for human distance traveled from Earth. It will take a minimum of ten days to complete the mission.

Artemis III

On March 26, 2019, the Vice President announced at a meeting of the National Space Council in Huntsville, AL, that, at the direction of the President, it is the stated policy of the United States of America to return American astronauts to the Moon within five years and that when American astronauts return to the lunar surface, they will take their first steps on the Moon's South Pole. The Artemis III mission will send the first crew to the lunar surface using a commercially-developed human landing system that will depart from the Gateway outpost orbiting the Moon. With the rapid development of the integrated human landing system and the Gateway, we will have access to more of the Moon than ever before. On May 13, 2019, NASA submitted a revised FY 2020 budget to Congress that would provide an additional "down payment" of $1.6 billion beyond the original budget request to achieve this objective. Our approach is to leverage and build upon our existing work to achieve these new goals.

NASA is now in the fabrication and assembly phase of developing SLS, Orion, and EGS, and is focused on bringing these capabilities together to conduct the first three Artemis missions. The Agency is incentivizing speed and drawing on commercial and international partners as it looks to land humans on the Moon within five years. NASA is completing development of the Orion spacecraft that will carry humans to lunar orbit, the SLS rocket that will launch Orion, and the Exploration Ground Systems that will support the Artemis missions.

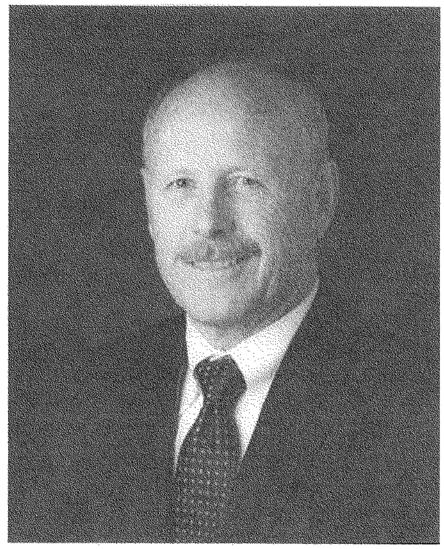
Conclusion

NASA is going forward to the Moon and Mars. With our U.S. industry and international partners, we are building a sustainable, open architecture that returns humanity to our nearest neighbor as the next step in our goal to establish a long-term human presence on the Moon before embarking on human missions to Mars. We are moving fast; we are incentivizing speed to land humans on the Moon within five years. We are using new acquisition strategies to engage the best of U.S. industry to meet our ambitious goals. We are completing development of SLS, Orion, and EGS. We are pressing forward toward uncrewed and crewed test flights of Orion around the Moon and we are working to land U.S. astronauts on the lunar South Pole by 2024. The lunar Gateway will serve as a reusable command module, supporting repeated human missions to the surface of the Moon, enabling opportunities to access to the entire lunar surface, and supporting human missions to Mars.

A sustainable lunar presence will pay dividends across diverse areas, including American leadership, scientific discovery, technology development, expansion of the economy, and inspiration of the next generation of STEM professionals. We have asked Congress for additional resources to get to the Moon by 2024, which will enable us to get to Mars more quickly and safely. The work we accomplish at the Moon over the next decade and beyond will ensure we can send the first humans to Mars. By focusing on accelerating our near-term efforts to land the first woman and the next man on the Moon in 2024, we will not only begin to realize these benefits sooner, we'll also create momentum that will reduce the political risk of disruptive changes in direction.

Chairwoman Horn and Ranking Member Babin, I would be happy to respond to any questions you or the other Members of the Subcommittee may have.

Kenneth Bowersox, Associate Administrator (Acting) for Human Exploration and Operations



Kenneth Bowersox was named acting associate administrator for NASA's Human Exploration and Operations Mission Directorate on July 10, 2019. Before being appointed to that position, Bowersox served for over five years as the Chair of the NASA Advisory Council's Human Exploration and Operations Committee, as well as Interim Chair of the NASA Advisory Council from June 2016 to January 2017. He is a retired U.S. Naval Aviator, with over 19 years of experience at the National Aeronautics and Space Administration (NASA). Selected to the astronaut corps in 1987, he has flown five times on NASA's Space Shuttle, serving as pilot, commander and mission specialist, and once on a Russian Soyuz, where he served as the flight engineer during descent. During his five orbital missions, Bowersox has logged over 211 days in space, including five and a half months aboard the International Space Station (ISS), where he was the mission commander of the 6th expedition. He was also a crew member for the first two Hubble Space Telescope repair flights and two United States Microgravity Laboratory flights.

Subsequent to his mission aboard the ISS, Bowersox served as the director of the Johnson Space Center's Flight Crew Operations Directorate, retiring from NASA and the U.S. Navy in December, 2006. After retirement, he remained involved with the U.S. space exploration program as a member of the standing review boards for ISS, Space Shuttle, and the Constellation Program. From 2009-2011, Bowersox was the Vice President of Astronaut Safety and Mission Assurance at SpaceX. Prior to his current assignment, Ken worked as an independent technical consultant, advising clients on spacecraft design, proposal development, and providing independent assessment of technical programs.

September 2019

Chairwoman HORN. Thank you, Mr. Bowersox. Ms. Chaplain, you're recognized.

TESTIMONY OF CRISTINA CHAPLAIN, DIRECTOR, CONTRACTING AND NATIONAL SECURITY ACQUISITIONS, U.S. GOVERNMENT ACCOUNTABILITY OFFICE

Ms. CHAPLAIN. Thank you. Chairman Horn, Ranking Member Babin, Chairwoman Johnson, Ranking Member Lucas, thank you for inviting me today to discuss the Space Launch System, Orion Crew Capsule, and supporting ground systems. We last reported on the status of these programs in June 2019, and I recognize there's been some noteworthy progress since our work. The successful test of Orion's launch abort system is one example.

However, we've been auditing these programs for about 5 years and have consistently raised concerns about management. I'd like to highlight three concerns that remain today.

First, the schedule has always been too optimistic. Before a baseline was set, it was envisioned the first launch of SLS would occur in December 2017. NASA appropriately recognized that date was unrealistic when it committed to a date for Congress, but that November 2018 baseline date was also too optimistic. NASA reset that date to no later than June 2020, and within a year, we found that it was unlikely that this date could be met. NASA is once again reviewing its launch dates at this time.

Second, costs have not been transparent. For 5 years we've only had cost estimates for the first flight of SLS and the second flight of Orion. We do not know what these programs will cost over time or what each launch will cost. We do not have ranges of what costs would be for certain types of missions. Most recently, we found that updates to the estimate for SLS and Orion were underreporting costs. For example, NASA moved hundreds of millions of dollars of costs away from the SLS estimate because it believed they were tied more to future missions, but it did not change the baseline cost estimate. This had the effect of distorting cost growth. Moreover, without baselines for future costs, there's no way to account for the costs that were shifted out. In other words, we cannot easily track what's being spent right now on the future. NASA is also reviewing its cost estimates at this time. We do not know if the future—the next estimates will cover future costs.

Third, programs have been consistently run with low levels of cost and schedule reserves. Human spaceflight programs face a wide range of inherent technical design and engineering risks. Many problems that will be encountered are not always easy to anticipate. The best way to prepare for these risks is to set aside cost and schedule reserves. NASA has done so for other major projects, which has contributed to better acquisition performance.

Reserves are not a panacea. We still see that even programs with healthy reserves such as the James Webb Telescope can still experience considerable costs and schedule growth. But not providing reserves exacerbates an already risky situation. At the same time, it's important to recognize that there are external factors such as funding requests or decisions that may not match development needs that help influence this practice.

We have other concerns about these programs as well. For example, contracts are not definitized for many months, which limited NASA's ability to manage contractor performance. When performance was not good, contractors still received award fees. Quality and workmanship problems contributed to many months of rework and delay. It's unrealistic to think that cost and schedule growth can be prevented altogether, but better management practice can help reduce the impacts of problems that arise.

My statement details practices that can be adopted. I'd like to emphasize a few key ones. First, in starting new efforts, it's important to maximize competition and have a long-term strategy or vision that can help guide technology design and requirements decisions. Congress and the Administration need to be key players in the long-term strategy development.

In managing programs, contracts need to be structured to provide the right incentives at the right times, and contractor oversight needs to be optimized. This can be done by breaking large contracts into smaller pieces using earned value management analyses to track performance, and having insight into quality management practices, as well as rewarding good performance and not rewarding poor performance.

Last, to meet the challenge of going to the Moon by 2024, it may be necessary for NASA to take on more schedule risks and to conduct many activities concurrently. Having backup plans will be key to managing these risks, as well as establishing good configuration management practices, detailed architectures to help guide and manage decisions, and candid reporting to Congress, especially as problems occur.

This concludes my statement, and I'm happy to answer any questions you have.

[The prepared statement of Ms. Chaplain follows:]

United States Government Accountability Office

GAO

Testimony

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

For Release on Delivery
Expected at 10:00 a.m. ET
Wednesday, September 18, 2019

NASA

Actions Needed to Improve the Management of Human Spaceflight Programs

Statement of Cristina T. Chaplain, Director,
Contracting and National Security Acquisitions

GAO-19-716T

GAO Highlights

Highlights of GAO-19-716T, a testimony before the Subcommittee on Space and Aeronautics, Committee on Science, Space, and Technology, House of Representatives

Why GAO Did This Study

NASA is undertaking a trio of closely related programs to continue human space exploration beyond low-Earth orbit. These three programs include a launch vehicle, a crew capsule, and the associated ground systems at Kennedy Space Center. All three programs are working towards a launch readiness date of June 2020 for the first mission. NASA then plans for these systems to support future human space exploration goals, which include seeking to land two astronauts on the lunar surface. GAO has a body of work highlighting concerns over NASA's management and oversight of these programs.

This statement discusses (1) the cost and schedule status of NASA's human spaceflight programs and (2) lessons that NASA can apply to improve its management of its human spaceflight programs. This statement is based on eight reports issued from 2014 to 2019 and selected updates as of September 2019. For the updates, GAO analyzed recent program status reports on program progress.

What GAO Recommends

GAO has made 19 recommendations in these eight prior reports to strengthen NASA's acquisition management of SLS, Orion, and EGS. NASA generally agreed with GAO's recommendations, and has implemented seven recommendations. Further action is needed to fully implement the remaining recommendations.

View GAO-19-716T. For more information, contact Cristina T. Chaplain at (202) 512-4841 or chaplainc@gao.gov.

September 18, 2019

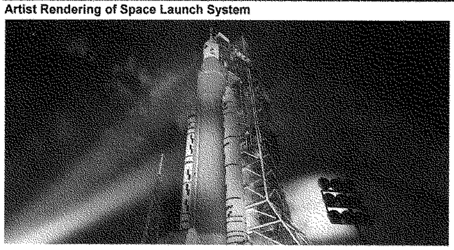
NASA

Actions Needed to Improve the Management of Human Spaceflight Programs

What GAO Found

The National Aeronautics and Space Administration's (NASA) three related human spaceflight programs are in the integration and test phase of development, a phase of the acquisition process that often reveals unforeseen challenges leading to cost growth and schedule delays. Since GAO last reported on the status of these programs in June 2019, each program has made progress. For example, the Orion program conducted a key test to demonstrate the ability to abort a mission should a life-threatening failure occur during launch. As GAO found in June 2019, however, the programs continue to face significant schedule delays. In November 2018, within one year of announcing an up to 19-month delay for the three programs—the Space Launch System (SLS) vehicle, the Orion crew spacecraft, and Exploration Ground Systems (EGS)—NASA senior leaders acknowledged the revised launch date of June 2020 is unlikely. In addition, any issues uncovered during integration and testing may push the date as late as June 2021. Moreover, GAO found that NASA's calculations of cost growth for the SLS program is understated by more than 750 million dollars.

Artist Rendering of Space Launch System



Source: National Aeronautics and Space Administration. | GAO-19-716T

GAO's past work has identified a number of lessons that NASA can apply to improve its management of its human spaceflight programs. For example, NASA should enhance contract management and oversight to improve program outcomes. NASA's past approach in this area has left it ill-positioned to identify early warning signs of impending schedule delays and cost growth or reap the benefits of competition. In addition, NASA's approach to incentivizing contractors through contract award fees did not result in desired outcomes for the SLS and Orion programs. Further, NASA should minimize risky programmatic decisions to better position programs for successful execution. This includes providing sufficient cost and schedule reserves to, among other things, address unforseen risk. Finally, realistic cost estimates and assessments of technical risk are particularly important at the start of an acquisition program. But NASA has historically provided little insight into the future cost of these human spaceflight programs, limiting the information useful to decision makers.

Chairwoman Horn, Ranking Member Babin, and Members of the Subcommittee:

I am pleased to be here today to discuss the National Aeronautics and Space Administration's (NASA) management of its human space exploration programs. These programs are developing the systems that will enable the agency to achieve its human space exploration goals, which include seeking to land two astronauts on the lunar surface as soon as 2024. The focus of my statement today is on three programs that will contribute to achieving this goal:

- The Space Launch System (SLS) program is developing a vehicle to launch a crew capsule and cargo beyond low-Earth orbit.
- The Orion Multi-Purpose Crew Vehicle (Orion) program is developing a crew capsule to transport humans beyond low-Earth orbit.
- The Exploration Ground Systems (EGS) program is developing systems and infrastructure to support assembly, test, and launch of the SLS and Orion crew capsule, and recovery of the Orion crew capsule.

Each of these programs represents a large, complex technical and programmatic endeavor and is currently in the integration and test phase of development. Our prior work has shown this phase of the acquisition process often reveals unforeseen challenges leading to cost growth and schedule delays.[1]

GAO has designated NASA's management of acquisitions as a high-risk area for almost three decades. In our March 2019 high-risk report, we reported there was a lack of transparency in NASA's major project cost and schedules, especially for its human spaceflight programs.[2] We reported that the agency has not taken action on several recommendations related to understanding the long-term costs of its

[1]GAO, *Space Launch System: Resources Need to be Matched to Requirements to Decrease Risk and Support Long Term Affordability,* GAO-14-631 (Washington, D.C.: Jul. 23, 2014); *Space Launch System: Management Tools Should Better Track to Cost and Schedule Commitments to Adequately Monitor Increasing Risk,* GAO-15-596 (Washington, D.C.: Jul. 16, 2015); and *James Webb Space Telescope: Project on Track but May Benefit from Improved Contractor Data to Better Understand Costs,* GAO-16-112 (Washington, D.C.: Dec. 17, 2015).

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

human exploration programs. For example, EGS and SLS do not have a cost and schedule baseline that covers activities beyond the first planned flight, and Orion does not have a baseline beyond the second planned flight. We have previously reported that without transparency into these estimates, NASA does not have the data to assess long-term affordability and it may be difficult for Congress to make informed budgetary decisions.[3] Moreover, while human spaceflight programs have inherent technical, design, and integration risks, we have consistently found that management and oversight problems are the real drivers behind program cost and schedule growth.

My statement today discusses (1) the cost and schedule status of NASA's human spaceflight programs and (2) lessons that NASA can apply to improve its management of its human spaceflight programs. This statement is based primarily on work completed from eight GAO reports issued from May 2014 through June 2019.[4] To conduct our prior work on the cost and schedule performance of these programs, we compared cost and schedule estimates that were current as of the reporting timeframes in our June 2019 report to their original cost and schedule baselines, analyzed quarterly program status reports, interviewed NASA program and headquarters officials, and reviewed program documentation. To identify lessons that can be applied to NASA's management of human spaceflight programs, we reviewed issues and recommendations made in our prior reports such as those related to approaches to managing contractors and incentivizing contractor performance, the quality of the cost and schedule estimates, and long-term cost estimates. Detailed information on the objectives, scope, and methodologies for that work is included in each of the reports that are cited throughout this statement. We updated the progress the programs have made with information

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

[4]GAO, *NASA Human Space Exploration: Persistent Delays and Cost Growth Reinforce Concerns over Management of Programs, GAO-19-377 (Washington, D.C.: Jun.19, 2019); NASA Human Space Exploration: Delay Likely for First Exploration Mission*, GAO-17-414 (Washington, D.C.: Apr. 27, 2017); *NASA Human Space Exploration: Opportunity Nears to Reassess Launch Vehicle and Ground Systems Cost and Schedule*, GAO-16-612 (Washington, D.C.: July 27, 2016); *Orion Multi-Purpose Crew Vehicle: Action Needed to Improve Visibility into Cost, Schedule, and Capacity to Resolve Technical Challenges*, GAO-16-620 (Washington, D.C.: Jul. 27, 2016); GAO-14-385; GAO-14-631; GAO-15-596; GAO-19-157SP.

obtained from NASA programs' quarterly reports since June 2019, where available.

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.

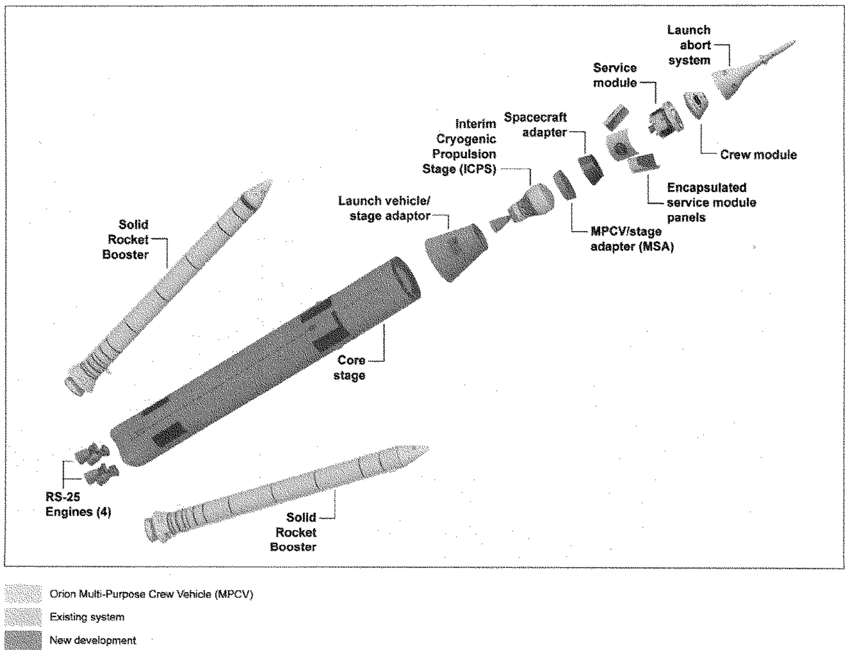
Background

The NASA Authorization Act of 2010 directed NASA to develop SLS, to continue development of a crew vehicle, and to prepare infrastructure at Kennedy Space Center to enable processing and launch of the launch system.[5] To fulfill this direction, NASA formally established the SLS launch vehicle program in 2011. Then, in 2012, NASA aligned the requirements for the Orion program with those of the newly created SLS and EGS programs.[6] Figure 1 provides details about each SLS hardware element and its source as well as identifies the major portions of the Orion spacecraft.

[5]Pub. L. No. 111-267, §§ 302, 303, and 305.

[6]The Orion program began as part of NASA's Constellation program aimed at developing a human spaceflight system. The Constellation program was cancelled, however, in 2010 due to factors that included cost and schedule growth and funding gaps.

Figure 1: Space Launch System and Orion Multi-Purpose Crew Vehicle Hardware



Source: GAO analysis of National Aeronautics and Space Administration data (data and images). | GAO-19-716T

History of Program Cost and Schedule Changes

In order to facilitate Congressional oversight and track program progress, NASA establishes an agency baseline commitment—the cost and schedule baselines against which the program may be measured—for all projects that have a total life cycle cost of $250 million or more. NASA refers to these projects as major projects or programs. When the NASA

Administrator determines that development cost growth within a major project or program is likely to exceed the development cost estimate by 15 percent or more, or a program milestone is likely to be delayed from the baseline's date by 6 months or more, NASA replans the project and submits a report to this committee—the Committee on Science, Space, and Technology of the House of Representatives—and the Committee on Commerce, Science, and Transportation of the Senate.[7] Should a major project or program exceed its development cost baseline by more than 30 percent, the program must be reauthorized by the Congress and rebaselined by NASA in order for the contractor to continue work beyond a specified time frame.[8] NASA tied the SLS and EGS program cost and schedule baselines to the uncrewed first mission—known now as Artemis-1—originally planned for November 2018. The Orion program's cost and schedule baselines are tied to a crewed second mission—known as Artemis-2—planned for April 2023.

In April 2017, we found that given combined effects of ongoing technical challenges in conjunction with limited cost and schedule reserves, it was unlikely that these three programs would achieve the originally committed November 2018 launch readiness date.[9] Cost reserves are for costs that are expected to be incurred—for instance, to address project risks—but are not yet allocated to a specific part of the project. Schedule reserves are extra time in project schedules that can be allocated to specific activities, elements, and major subsystems to mitigate delays or address unforeseen risks. We recommended that NASA confirm whether the November 2018 launch readiness date was achievable and, if warranted, propose a new, more realistic Artemis-1 date and report to Congress on the results of its schedule analysis. NASA agreed with both recommendations and stated that it was no longer in its best interest to pursue the November 2018 launch readiness date. Subsequently, NASA approved a new Artemis-1 schedule of December 2019, with 6 months of schedule reserve available to extend the date to June 2020, and revised the costs that it expects to incur (see table 1).

[7]51 U.S.C. § 30104.

[8]51 U.S.C. § 30104(e)(2), (f).

[9]GAO-17-414.

Table 1: Human Space Exploration Program Baselines and Current Plans (costs in billions)

	Agency Baseline Commitment		Replan (December 2017)		Development percentage cost growth	Delay (Months)
	Development Cost	Launch Date	Development Cost	Launch Date		
Space Launch System	$7.021	November 2018 Artemis-1	$7.169	December 2019–June 2020 Artemis-1	2.1%	13-19
Exploration Ground Systems	$1.843	November 2018 Artemis-1	$2.265	December 2019-June 2020 Artemis-1	22.9%	13-19
Orion Multi-Purpose Crew Vehicle	$6.768	April 2023 Artemis-2	Not applicable because Orion's performance is measured to Artemis-2.			

Source: GAO presentation of National Aeronautics and Space Administration data. | GAO-19-716T

Cost and Schedule Status of NASA's Human Spaceflight Programs

In June 2019, we found that within 1 year of announcing a delay for the first human spaceflight mission, senior NASA officials acknowledged that the revised Artemis-1 launch date of December 2019 was unachievable and the June 2020 launch date (which takes into account schedule reserves) was unlikely.[10] These officials estimated that there were 6 to 12 months of schedule risk associated with this later date, which means the first launch may occur as late as June 2021 if all risks are realized. As we found in June 2019, this would be a 31-month delay from the schedule originally established in the programs' baselines. Officials attributed the additional schedule delay to continued production challenges with the SLS core stage and the Orion crew and service modules. NASA officials also stated that the 6 to 12 months of risk to the launch date accounts for the possibilities that SLS and Orion testing and final cross-program integration and testing at Kennedy Space Center may result in further delays. As we noted in our report, these 6 to 12 months of schedule risk do not include the effects, if any, of the federal government shutdown that occurred in December 2018 and January 2019.

In commenting on our June 2019 report, NASA stated that its Lunar 2024 planning activities would include an Artemis-1 schedule assessment.[11] However, in July 2019, NASA reassigned its senior leaders responsible for human spaceflight programs. The NASA Administrator stated in

[10]GAO-19-377.

[11]GAO-19-377.

August 2019 that, as a result, the agency does not plan to finalize schedule plans for Artemis-1 until new leadership is in place at the agency. Additional details follow on the status of each program, including cost, schedule, and technical challenges.

SLS. As we found in June 2019, ongoing development issues with the SLS core stage—which includes four main engines and the software necessary to command and control the vehicle—contributed to the SLS program not being able to meet the June 2020 launch date.[12] Officials from the SLS program and Boeing, the contractor responsible for building the core stage, provided several reasons for the delays. These reasons include the underestimation of the complexity of manufacturing and assembling the core stage engine section—where the RS-25 engines are mated to the core stage—and those activities have taken far longer than expected.

Since our June 2019 report, based on our review of the program's most recent status reports, NASA has reported progress across many parts of the SLS program. For example, NASA has delivered the four RS-25 engines to Michoud Assembly Facility. NASA has also completed qualification testing of all components of the boosters and reports that there is schedule margin remaining for the booster deliverables. In addition, NASA reports that Boeing has made continued progress and expects that the core stage will be complete and ready for testing in December 2019. Completion of the core stage will represent a significant milestone for the program.

In June 2019, we found that that SLS program has been underreporting its development cost growth since the December 2017 replan.[13] This underreporting is because of a decision to shift some costs to future missions while not adjusting the baseline costs downward to reflect this shift. The SLS development cost baseline established in August 2014 for Artemis-1 includes cost estimates for the main vehicle elements—stages, liquid engines, boosters—and other areas. According to program officials, because of the December 2017 replan process, NASA decided that costs included as part of the SLS Artemis-1 baseline cost estimate would be more appropriately accounted for as costs for future flights. Thus, NASA decided not to include those costs, approximately $782 million, as part of

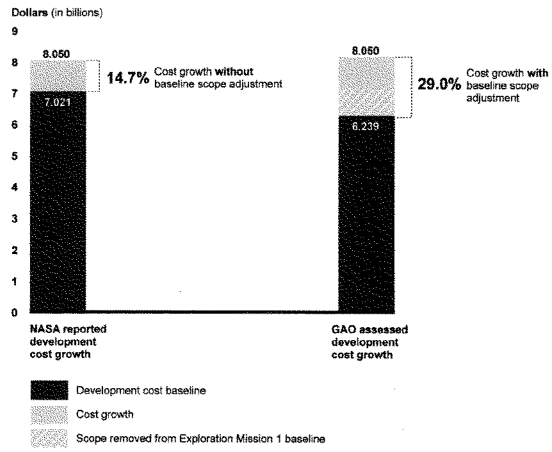
[12]GAO-19-377.

[13]GAO-19-377.

the revised SLS Artemis-1 cost estimate. However, NASA did not lower the $7 billion SLS development cost baseline to account for this significant change in assumptions and shifting of costs to future flights.

This decision presents challenges in accurately reporting SLS cost growth over time. NASA's decision not to adjust the cost baseline downward to reflect the reduced mission scope obscures cost growth for Artemis-1. In June 2019, we found that NASA's cost estimate as of fourth quarter fiscal year 2018 for the SLS program indicated development cost growth had increased by $1 billion, or 14.7 percent. However, our analysis showed that development cost growth actually increased by $1.8 billion or 29.0 percent, when the development baseline is lowered to account for the reduced mission scope. Essentially, NASA is holding the baseline costs steady, while reducing the scope of work included in current cost estimates (see figure 2). As NASA determines its new schedule for the first mission, it is likely this cost growth will increase as additional time in the schedule leads to additional costs.

Figure 2: NASA's Reported Development Cost Growth for Space Launch System Compared to GAO's Assessed Development Cost Growth, as of September 2018



Source: GAO analysis of National Aeronautics and Space Administration data. | GAO-19-716T

In our June 2019 report, we recommended that the SLS program calculate its development cost growth using a baseline that is appropriately adjusted for scope and costs NASA has determined are not associated with the first flight, and determine if the development cost growth has increased by 30 percent or more. NASA agreed with the recommendation and NASA officials stated that they plan to implement the recommendation when new leadership is in place for the human space exploration programs.

Looking ahead, based on our review of the program's most recent status reports, completing core stage manufacturing and integration and green run testing will be the critical path—the path of longest duration through the sequence of activities in the schedule—for the SLS program. During green run testing, NASA will fuel the completed core stage with liquid hydrogen and liquid oxygen and fire the integrated four main engines for about 500 seconds. The green run test carries risks because it is the first time that several things are being done beyond just this initial fueling. For example, it is also the first time NASA will fire the four main engines together, test the integrated engine and core stage auxiliary power units in flight-like conditions, and use the SLS software in an integrated flight vehicle. In addition, NASA will conduct the test on the Artemis-1 flight vehicle hardware, which means the program would have to repair any damage from the test before flight.

Orion. While the Orion program's schedule performance is measured only to the Artemis-2 mission, we found in June 2019 that the program was not on schedule to support the June 2020 launch date for the first mission.[14] This was due to delays with the European Service Module and component issues for the avionics systems for the crew module, including issues discovered during testing. We found that these specific problems were resolved by the time of our report, but had already contributed to the inability of the program to meet the June 2020 launch date. Since we last reported, as of August 2019, the Orion program has completed significant events including completing the crew module and the service module prior to integration and conducting a test to demonstrate the ability to abort a mission should a life-threatening failure occur during launch. The program is tracking no earlier than October 2020 for an Artemis-1 launch date but that does not reflect the ongoing agency-wide schedule assessment noted above.

In June 2019, we found that the Orion program has reported development cost growth but is not measuring that growth using a complete cost estimate.[15] In summer 2018, the Orion program reported development cost growth of $379 million, or 5.6 percent above its $6.768 billion development cost estimate. Program officials explained that the major drivers of this cost growth were the slip of the Artemis-1 launch date, which reflected delays in the delivery of the service module; Orion contractor underperformance; and NASA-directed scope increase.

However, during our review, Orion program officials originally stated that this cost estimate assumes an Artemis-2 launch date of September 2022, which is 7 months earlier than the program's agency baseline commitment date of April 2023 that forms the basis for commitments between NASA, the Congress, and Office of Management and Budget.

[14]GAO-19-377.

[15]GAO-19-377.

Subsequently, during the review, program officials told us that its cost projections fund one of those 7 months. In either case, NASA's current cost estimate for the Orion program is not complete because it does not account for costs that NASA would incur through April 2023. As of September 2019, the program was targeting October 2022 for the Artemis-2 launch.

In June 2019, we recommended that the Orion program update its cost estimate to reflect its committed Artemis-2 baseline date of April 2023.[16] In its response, NASA partially agreed with our recommendation. NASA stated that providing the estimate to the forecasted launch date—September 2022—rather than to the committed baseline date of April 2023 is the most appropriate approach. However, by developing cost estimates only to the program's goals and not relative to the established baseline, the Orion program is not providing NASA or the Congress the means of measuring progress relative to the baseline. We continue to believe that NASA should fully implement this recommendation.

Looking ahead, based on our review of the program's most recent status reports, there is an emerging issue that may delay schedule further for the first mission. Namely, there is the risk of damage to the Orion capsule during travel to and from integrated testing at Plum Brook Station in Ohio. The program office is studying whether it will be able to safely transport the integrated crew and service modules via the Super Guppy airplane as planned or if it will have to use an alternate airplane. We will continue to monitor this effort.

Beyond Artemis-1, the Orion program must also complete development efforts for future missions. For example, the Artemis-2 crew module will need environmental control and life support systems, system updates from Artemis-1, and updated software to run these new elements.

EGS. At the time of our June 2019 report, the EGS program was expecting to have facilities and software ready by the planned June 2020 launch date.[17] We found that the program had overcome many challenging development hurdles that led to previous schedule delays. These hurdles included completing and moving the Mobile Launcher—a platform that carries the rocket to the launch pad and includes a number

[16]GAO-19-377.

[17]GAO-19-377.

of connection lines that provide SLS and Orion with power, communications, coolant, fuel, and stabilization prior to launch—into the Vehicle Assembly Building for the multi-element verification and validation processes. Since our June 2019 report, the program is now targeting an Artemis-1 launch date of August 2020. According to NASA officials, the delay is primarily driven by challenges encountered installing ground support equipment on the Mobile Launcher and developing software, and does not reflect the ongoing agency-wide schedule assessment. The program has operated within the costs established for the June 2020 launch date, $3.2 billion, but officials stated that NASA is reevaluating the program's development cost performance and will establish an updated baseline when new leadership is in place.

Moving forward, based on our review of the program's most recent status reports, the program has to complete the multi-element verification and validation process for the Mobile Launcher and Vehicle Assembly Building and complete its two software development efforts. Additionally, the EGS program is responsible for the final integration of the three programs. NASA officials stated that the 6 to 12 months of risk to the June 2020 launch date includes risk associated with EGS completing this integration that includes test and checkout procedures after SLS and Orion components arrive. Officials explained that the EGS risk is based on a schedule risk analysis that considered factors such as historical pre-launch integrated test and check out delays and the learning curve associated with a new vehicle. As previously stated, our prior work has shown that the integration and test phase often reveals unforeseen challenges leading to cost growth and schedule delays.

Lessons that NASA Can Apply to Better Manage its Human Spaceflight Acquisitions

NASA is currently embarking on an aggressive goal to return humans to the lunar surface in 2024. To achieve this goal, NASA not only needs SLS, Orion, and EGS to have completed their first two test missions, but is also developing several new systems. These new systems include a Lunar Gateway that will orbit the moon, landers that will transport astronauts from the Gateway to the lunar surface, and new space suits.

Human spaceflight projects face inherent technical, design, and integration risks because they are complex, specialized, and are pushing the state of the art in space technology. Moreover, these programs can be very costly and span many years, which means they may also face changes in direction from Administrations and the Congress. Meeting the 2024 goal will also be challenging given the effort needed to better manage SLS, Orion, and EGS, coupled with the addition of the new programs, which are likely to compete for management attention and resources. Nevertheless, our past work has identified a range of actions that NASA can take to better position its human spaceflight programs for success.

Today I would like to highlight three lessons from the SLS, Orion, and EGS programs that NASA can apply to improve the management of its human spaceflight programs.

Enhance Contract Management and Oversight to Improve Program Outcomes. Over the past several years, we and the NASA Office of the Inspector General have identified shortcomings related to NASA's management and oversight of its human spaceflight contracts. These shortcomings have left NASA ill-positioned to identify early warning signs of impending schedule delays and cost growth, reap the potential benefits of competition, and achieve desired results through contractor incentives.

- In July 2014, we found that NASA allowed high-value modifications to the SLS contracts to remain undefinitized for extended periods—in one instance a modification remained undefinitized for 30 months.[18] Undefinitized contract actions such as these authorize contractors to begin work before reaching a final agreement with the government on terms and conditions. We have previously found that while undefinitized contract actions may be necessary under certain circumstances, they are considered risky in part because the government may incur unnecessary costs if requirements change before the contract action is definitized.[19] Because lack of agreement on terms of the modification prolonged NASA's timeframes for definitizing, the establishment of contractor cost and schedule baselines necessary to monitor performance was delayed. Specifically, we found in July 2014 that, in most cases, the SLS program did not receive complete earned value management data derived from approved baselines on these SLS contracts. Earned value, or the planned cost of completed work and work in progress, can provide accurate assessments of project progress, produce early

[18]GAO-14-631.

[19]GAO, *Missile Defense: The Warfighter and Decision Makers Would Benefit from Better Communication About the System's Capabilities and Limitations,* GAO-18-324 (Washington, D.C.: May 30, 2018).

warning signs of impending schedule delays and cost overruns, and provide unbiased estimates of anticipated costs at completion.[20]

- In July 2014, we also found the SLS program could be in a favorable position to compete contracts for the exploration upper stage, the upper stage engine, and advanced boosters that it expected to use on future variants of the launch vehicle.[21] At that time, except for the RS-25 engines, NASA's contracting approach for the SLS program did not commit the program beyond the hardware needed for the second mission, and we found that moving forward the agency would be in a position to take advantage of the evolving launch vehicle market. We found that an updated assessment of the launch vehicle market could better position NASA to sustain competition, control costs, and better inform the Congress about the long-term affordability of the program. We recommended that before finalizing acquisition plans for future capability variants, NASA should assess the full range of competition opportunities and provide to the Congress the agency's assessment of the extent to which development and production of future elements of the SLS could be competitively procured. NASA agreed with the recommendation, which we have identified as among those that warrant priority attention.[22]

  Since we made that recommendation, NASA has awarded a sole-source contract for the upper stage engine and agency officials told us in July 2018 that they planned to incorporate additional booster development under the existing contract. This further limits an opportunity for competition for the program. Our body of work on contracting has shown that competition in contracting is a key element for achieving the best return on investment for taxpayers.[23] We have

[20]GAO-14-631.

[21]GA-14-631.

[22]We send letters each year to the heads of key departments and agencies, including NASA, that give the overall status of the department's or agency's implementation of our recommendations and identify open recommendations that should be a priority for implementation. In April 2019, we sent the Administrator of NASA this year's letter, which identified nine recommendations as being a priority for implementation. See GAO, *Priority Open Recommendations: National Aeronautics and Space Administration*, GAO-19-424SP (Washington, D.C.: Apr. 12, 2019).

[23]See, for example, GAO, *Federal Contracting: Noncompetitive Contracts Based on Urgency Need Additional Oversight*, GAO-14-304 (Washington, D.C.: Mar. 26, 2014); *Defense Contracting: Actions Needed to Increase Competition*, GAO-13-325 (Washington, D.C.: Mar. 28, 2013); and *Federal Contracting: Opportunities Exist to Increase Competition and Assess Reasons When Only One Offer Is Received*, GAO-10-833 (Washington, D.C.: Jul. 26, 2010).

found that promoting competition increases the potential for acquiring quality goods and services at a lower price and that noncompetitive contracts carry the risk of overspending because, among other reasons, they have been negotiated without the benefit of competition to help establish pricing.

- In July 2016, we found that the lack of earned value management data for the SLS Boeing core stage contract persisted.[24] Without this information, some 4.5 years after contract award, the program continued to be in a poor position to understand the extent to which technical challenges with the core stage were having schedule implications or the extent to which they may have required reaching into the program's cost reserves.
- In October 2018, the NASA Office of Inspector General reported that NASA does not require Boeing to report detailed information on development costs for the two core stages and exploration upper stage, making it difficult for the agency to determine if the contractor is meeting cost and schedule commitments for each deliverable.[25] The NASA Office of Inspector General found that given the cost-reporting structure, the agency is unable to determine the cost of a single core stage. Internally, Boeing tracks all individual costs but submits a combined statement of labor hours and material costs through the one contract line item for all its development activities. NASA approximates costs based on numerous monthly and quarterly reviews with the contractor to track the progress of each individual deliverable. The NASA Office of Inspector General made a number of recommendations aimed at improving reporting relative to the core stage contract. Among these was a specific recommendation to separate each deliverable into its own contract line item number for tracking performance, cost, and award fees. NASA concurred with this recommendation and is currently renegotiating the core stage contract with Boeing.
- In June 2019, we found that NASA's approach to incentivizing Boeing for the SLS stages and Lockheed Martin for the Orion crew spacecraft have not always achieved overall desired program outcomes.[26] NASA

[24]GAO-16-612.

[25]NASA Office of Inspector General, NASA's Management of the Space Launch System Stages Contract, IG-19-001 (Washington, D.C.: Oct. 10, 2018).

[26]GAO-19-377.

paid over $200 million in award fees from 2014-2018 related to contractor performance on the SLS stages and Orion spacecraft contracts, but the programs continue to fall behind schedule and incur cost overruns. For example, in its December 2018 award fee letter to Boeing in which the contractor earned over $17 million in award fees, NASA's fee determination official noted that the significant schedule delays on this contract have caused NASA to restructure the flight manifest for SLS. For the Lockheed Martin Orion contract, the contractor earned over $29 million for the award fee period ending April 2017. NASA noted that Lockheed Martin was not able to maintain its schedule for the crew service module and that the contractor's schedule performance had decreased significantly over the previous year.

In June 2019, we reported that our past work shows that when incentive contracts are properly structured, the contractor has profit motive to keep costs low, deliver a product on time, and make decisions that help ensure the quality of the product. Our prior work also shows, however, that incentives are not always effective tools for achieving desired acquisition outcomes. We have found that, in some cases, there are significant disconnects between contractor performance for which the contractor was awarded the majority of award fees possible without achieving desired program results. Additionally, we have found that some agencies did not have methods, data, or performance measures to evaluate the effectiveness of award fees.[27]

As part of our June 2019 report, we recommended that NASA direct the SLS and Orion programs to reevaluate their strategies for incentivizing contractors and determine whether they could more effectively incentivize contractors to achieve the outcomes intended as part of ongoing and planned contract negotiations.[28] NASA agreed with the intent of this recommendation and stated that the SLS and Orion program offices reevaluate their strategies for incentivizing contract performance as part of contracting activities including

[27]GAO, *Defense Acquisitions: DOD Has Paid Billions in Award and Incentive Fees Regardless of Acquisition Outcomes*, GAO-06-66 (Washington, D.C.: Dec. 19, 2005); *NASA Procurement: Use of Award Fees for Achieving Program Outcomes Should Be Improved*, GAO-07-58 (Washington, D.C.: Jan. 17, 2007); and *Federal Contracting: Guidance on Award Fees Has Led to Better Practices but Is Not Consistently Applied*, GAO-09-630 (Washington, D.C.: May 29, 2009).

[28]GAO-19-377.

contract restructures, contract baseline adjustments, and new contract actions. We will continue to follow-up on the actions the agency is taking to address this recommendation after its ongoing contract negotiations are complete.

Minimize Risky Programmatic Decisions to Better Position Programs for Successful Execution. Through our reviews of NASA's human spaceflight programs, we have found that NASA leadership has approved programmatic decisions that compound technical challenges. These decisions include approving cost and schedule baselines that do not follow best practices, establishing insufficient cost and schedule reserves, and operating under aggressive schedules.[29] As a result, these programs have been at risk of cost growth and schedule delays since NASA approved their baselines.

- In July 2015, we found that NASA generally followed best practices in preparing the SLS cost and schedule baseline estimates for the limited portion of the program life cycle covered through launch readiness for the first test flight of SLS. However, we could not deem the cost estimate fully reliable because it did not fully meet the credibility best practice.[30] While an independent NASA office reviewed the cost estimate developed by the program and as a result the program made some adjustments, officials did not commission the development of a separate independent cost estimate to compare to the program cost estimate to identify areas of discrepancy or difference. In addition, the program did not cross-check its cost estimate using an alternative methodology. The purpose of developing a separate independent cost estimate and cross-checking the estimate is to test the program's cost estimate for reasonableness and, ultimately, to validate the cost estimate.
- In July 2016, we found that the Orion program's cost and schedule estimates were not reliable based on best practices for producing high-quality estimates.[31] For example, the cost estimate lacked necessary support and the schedule estimate did not include the level of detail required for high-quality estimates. Therefore, we

[29]GAO-15-596; GAO-16-620; GAO-16-612.

[30]GAO-15-596. A credible cost estimate is one that discusses any limitations of the analysis from uncertainty or biases surrounding data or assumptions.

[31]GAO-16-620.

recommended that NASA perform an updated joint cost and schedule confidence level analysis including updating cost and schedule estimates in adherence with cost and schedule estimating best practices, which we have identified as among those recommendations that warrant priority.[32] NASA officials have stated that they have no plans to implement our recommendation. In commenting on the July 2016 report, NASA stated that the agency reviewed, in detail, the Orion integrated cost/schedule and risk analysis methodology and determined the rigor to be a sufficient basis for the agency commitments. However, without sound cost and schedule estimates, decision makers do not have a clear understanding of the cost and schedule risk inherent in the program or important information needed to make programmatic decisions. We continue to believe that NASA should fully implement our recommendation.

- In our 2017 High-Risk Report, we highlighted concerns that all three programs—SLS, Orion, and EGS—were operating with limited cost reserves, limiting each program's ability to address risks and unforeseen technical challenges.[33] For example, we found in July 2016 that the Orion program was planning to maintain low levels of cost reserves until later in the program.[34] The lack of cost reserves at that time had caused the program to defer work to address technical issues to stay within budget.
- Also in our 2017 High-Risk Report, we highlighted concerns regarding each program managing to an aggressive internal NASA launch readiness date. This approach creates an environment for programs to make decisions based on reduced knowledge to meet a date that is not realistic.[35] For example, the EGS program had consolidated future schedule activities to prepare the Mobile Launcher—the vehicle used to bring SLS to the launch pad—to meet its internal goal. The program acknowledged that consolidating activities—which included conducting verification and validation concurrent with installation

[32]A joint cost and schedule confidence level analysis produces a point-in-time estimate that includes, among other things, all cost and schedule elements from concept and technology development through launch, incorporates and quantifies known risks, assesses the effects of cost and schedule to date on the estimate, and addresses available annual resources.

[33]GAO, *High-Risk Series: Progress on Many High-Risk Areas, While Substantial Efforts Needed on Others*, GAO-17-317 (Washington, D.C.: Feb. 15, 2017).

[34]GAO-16-612.

[35]GAO-17-317.

activities—increased risk because of uncertainties about how systems not yet installed may affect the systems already installed. Officials added, however, that this concurrency is necessary to meet the internal schedule. Subsequently, as discussed above, NASA delayed its committed launch readiness date.

Improve Transparency into Costs for Long-term Plans. As we previously reported, a key best practice for development efforts is that requirements need to be matched to resources (for example, time, money, and people) at program start.[36] In the past, we have found that NASA programs, including the Constellation Program, did not have sufficient funding to match demanding requirements.[37] Funding gaps can cause programs to delay or delete important activities and thereby increase risks.

In addition, since May 2014, we have found there has been a lack of transparency into the long-term costs of these human spaceflight programs.[38] As discussed above, the EGS and SLS programs do not have a cost and schedule baseline that covers activities beyond the first planned flight. In addition, as previously noted, the Orion program does not have a baseline beyond the second planned flight. As a result, NASA is now committing to spend billions of taxpayer dollars for missions that do not have a cost and schedule baseline against which to assess progress.

To that end, we have made recommendations in the past on the need for NASA to baseline these programs' costs for capabilities beyond the first mission; however, a significant amount of time has passed without NASA taking steps to fully implement these recommendations. Specifically, among those recommendations that we have identified as warranting priority attention, in May 2014, we recommended that, to provide Congress with the necessary insight into program affordability, ensure its ability to effectively monitor total program costs and execution, and to facilitate investment decisions, NASA should:

[36]GAO, *U.S. Launch Enterprise: Acquisition Best Practices Can Benefit Future Efforts*, GAO-14-776T (Washington, D.C: July 16, 2014).

[37]GAO, *NASA: Constellation Program Cost and Schedule Will Remain Uncertain Until a Sound Business Case Is Established*, GAO-09-844 (Washington, D.C.: Aug. 26, 2009) and GAO-14-385.

[38]GAO-14-385.

- Establish a separate cost and schedule baseline for work required to support the SLS for the second mission and report this information to the Congress through NASA's annual budget submission. If NASA decides to fly the SLS configuration used in the second mission beyond that mission, we recommended that it establish separate life cycle cost and schedule baseline estimates for those efforts, to include funding for operations and sustainment, and report this information annually to Congress via the agency's budget submission.
- Establish separate cost and schedule baselines for each additional capability that encompass all life cycle costs, to include operations and sustainment. This is important because NASA intends to use the increased capabilities of the SLS, Orion, and EGS well into the future.

As part of the latter recommendation, we stated that, when NASA could not fully specify costs due to lack of well-defined missions or flight manifests, the agency instead should forecast a cost estimate range—including life cycle costs—having minimum and maximum boundaries and report these baselines or ranges annually to Congress via the agency's budget submission.[39]

In its comments on our 2014 report, NASA partially concurred with these two recommendations, noting that much of what it had already done or expected to do would address them.[40] For example, the agency stated that establishing the three programs as separate efforts with individual cost and schedule commitments met the intent of our recommendation. NASA also stated that its plans to track and report development, operations, and sustainment costs in its budget to Congress as the capabilities evolved would also meet the intent of the recommendation. In our response, we stated that while NASA's prior establishment of three separate programs lends some insight into expected costs and schedule at the broader program level, it does not meet the intent of the two recommendations because cost and schedule identified at that level is unlikely to provide the detail necessary to monitor the progress of each block against a baseline. Further, we stated that reporting the costs via the budget process alone will not provide information about potential costs over the long term because budget requests neither offer all the same information as life-cycle cost estimates nor serve the same purpose. Life-cycle cost estimates establish a full accounting of all

[39]GAO-14-385.

[40]GAO-14-385.

program costs for planning, procurement, operations and maintenance, and disposal and provide a long-term means to measure progress over a program's life span.[41] We continue to believe that NASA should fully implement these recommendations.

As NASA considers these lessons, it is important that the programs place a high priority on quality, for example, holding suppliers accountable to deliver high-quality parts for their products through such activities as regular supplier audits and performance evaluations of quality and delivery. As we found in June 2019, both the SLS and Orion programs have struggled at times with the quality of parts and components.[42] For example, the Orion contractor has had a number of issues with subcontractor-supplied avionics system components failing during testing that have required time to address. NASA has highlighted concerns over the contractor's ability to manage its subcontractors and the resulting significant cost, schedule, and technical risk impacts to the program. And the SLS program faced setbacks after its contractor did not verify the processes that its vendors were using to clean the fuel lines, resulting in delays to resolve residue and debris issues.

Chairwoman Horn, Ranking Member Babin, and Members of the Subcommittee, this completes my prepared statement. I would be pleased to respond to any question 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 Cristina T. Chaplain, Director, Contracting and National Security Acquisitions at (202) 512-4841 or chaplainc@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this statement. GAO staff who made key contributions to this statement include Molly Traci, Assistant Director; John Warren; Sylvia Schatz; Ryan Stott; and Chad Johnson.

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

[42] GAO-19-377.

GAO's Mission

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

Obtaining Copies of GAO Reports and Testimony

The fastest and easiest way to obtain copies of GAO documents at no cost is through GAO's website (https://www.gao.gov). Each weekday afternoon, GAO posts on its website newly released reports, testimony, and correspondence. To have GAO e-mail you a list of newly posted products, go to https://www.gao.gov and select "E-mail Updates."

Order by Phone

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

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

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

Connect with GAO

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

To Report Fraud, Waste, and Abuse in Federal Programs

Contact FraudNet:

Website: https://www.gao.gov/fraudnet/fraudnet.htm

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

Congressional Relations

Orice Williams Brown, Managing Director, WilliamsO@gao.gov, (202) 512-4400, U.S. Government Accountability Office, 441 G Street NW, Room 7125, Washington, DC 20548

Public Affairs

Chuck Young, Managing Director, youngc1@gao.gov, (202) 512-4800
U.S. Government Accountability Office, 441 G Street NW, Room 7149
Washington, DC 20548

Strategic Planning and External Liaison

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

Cristina T. Chaplain

Ms. Chaplain currently serves as a Director, Contracting and National Security Acquisitions, at the U.S. Government Accountability Office. She has responsibility for GAO assessments of NASA, military space programs, and the Missile Defense Agency. Among other topics, she has recently led reviews on the Space Launch System the Orion crew capsule, acquisition progress for major NASA projects, the James Webb telescope, commercial cargo and crew, the Global Positioning System, cyber protection for weapons, and space leadership. In addition to her work on space and missile system development, Ms. Chaplain has led a variety of DOD-wide contracting-related and best practice evaluations for the GAO. Before her current position, Ms. Chaplain worked with GAO's financial management and information technology teams. Ms. Chaplain has been with the GAO for 28 years. She received a bachelor's degree, magna cum laude, in International Relations from Boston University and a Masters Degree in Journalism from Columbia University.

Chairwoman HORN. Thank you, Ms. Chaplain. Mr. Cooke.

TESTIMONY OF DOUG COOKE, OWNER, COOKE CONCEPTS AND SOLUTIONS, AND FORMER ASSOCIATE ADMINISTRATOR, EXPLORATION SYSTEMS, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. COOKE. Thank you, Chairwoman Horn, Ranking Member Babin, Chairwoman Johnson, and Ranking Member Lucas. Thank you also to the Members of the Committee for this opportunity to address the current state of deep space exploration. It is an endeavor I've devoted much of my life and career to. I truly appreciate your interest. I also thank the people at NASA and industry who work very hard every day to make these programs happen and successful.

I defer to Ken Bowersox for specifics of the program. I will focus on how SLS and Orion came into being for context and how they are being used.

What I consider to be the most straightforward approach to a near-term human lunar landing and management solutions from my experience in the Space Shuttle, Space station, and exploration programs given concerns in recent GAO reports and my own observations. There is much more extensive detail on all this in my written testimony.

The Space Launch System, Orion, and ground systems were designed based on goals, objectives, requirements, and constraints. At the highest level, space programs are guided by space policy from Administrations and Congress, which initiate the programs that enhance our national leadership, commerce, scientific knowledge, international relationships, and more. These objectives drive what capabilities and missions are needed. They lead to space and surface systems that will have to be transported.

For 30 years, human missions to the Moon and Mars have been envisioned in policy. Over this period, I've been part of or led much of the study and planning that has been done. All studies have led to the requirement for a capsule and a heavy lift vehicle as the most critical elements in the human exploration architecture. A blunt-shaped entry capsule with high-temperature materials is required for high velocities from the lunar and Mars distances. As an example, the Space Shuttle could not have survived.

A heavy lift vehicle on the order of 100 to 130 metric tons or more with a large payload volume is needed for the large heavy elements. Anything less overconstrains landers and habitats. The specific decision process and component choices for SLS are in my written testimony.

The fewer launches and critical operations per mission, the higher the probability of mission success. Documentaries of Apollo 11 during the 50th anniversary reminded me about how much anxious anticipation you have as each critical flight operation occurs knowing that failure can be mission-ending or life-threatening. It's also true in robotic missions. Recall the JPL (Jet Propulsion Laboratory) Curiosity Mission and "7 Minutes of Terror" as the team waited for the signal of the Mars landing.

NASA's current approach to the first lunar landing has numerous launches, one SLS carrying Orion and several more extended commercial launch vehicles with eight new flight elements, including Gateway elements. SLS is not used for the lander or ascent vehicles, and the lander even has to be fueled at the Gateway. Therefore, SLS is not being used for what it was designed to do other than carry Orion.

The approach has about 17 of these critical mission operations that have to go right for this first Moon mission to succeed. Based on past experience, it also seems high risk for eight new procurements and developments to succeed by the Administration's mandated 2024 landing date. If NASA focuses on the investment in the ongoing SLS with the EUS, Orion, and ground system developments, there is a better chance of making an earlier date. NASA should pursue an SLS payload shroud to get to 100-plus metric ton launch capability with the EUS. Then I believe a crew and less-constrained lander can be launched to the Moon with two SLS launches.

NASA can focus on new development energy on an integrated lander and surface spacesuit. That's still a lot to accomplish in new developments. The Gateway can be deferred until later, and there will be opportunities for commercial vehicles.

I recognize that there have been concerns and issues with these programs that the GAO and others have reported. There are delays. Based on my observations and reading the GAO reports, I believe a strong systems engineering integration effort across the program and a prime integration contractor are needed to improve reporting and to work problems on—problems on the interfaces expeditiously between program elements. It can maintain an accurate, integrated schedule tied to budget. It can provide the oversight where needed. This is what was done on the Space Station program between Space Station Freedom and the International Space Station programs. It was needed. These programs now are 24/7.

At this point there needs to be urgency to get them done. This is a time to bear down on these programs with strong leadership and the organizational structure to take advantage of investments we are making and achieve the earliest possible landing date with capabilities that lead to a sustainable exploration program. I welcome your questions. Thank you.

[The prepared statement of Mr. Cooke follows:]

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

"Developing Core Capabilities for Deep Space Exploration: an Update on SLS, Orion, and Exploration Ground Systems"

Wednesday, September 18, 2019

Testimony of Douglas R. Cooke
Cooke Concepts and Solutions

Thank you Chairwoman Horn and members of the committee for this opportunity to address the current state of Deep Space Exploration. It is a passion I have devoted much of my life and career to for many years. I feel a certain ownership and responsibility for the Space Launch System, the Orion Crew Vehicle and Exploration Ground Systems as well as many other aspects of our U. S. Space Program.

I began work at NASA just after Apollo, during the last flight to Skylab. I worked in critical positions on Space Shuttle, Space Station and Exploration Programs anticipating the day Americans would travel again and explore places like the Moon and Mars. I believe that NASA human space flight should focus on exploration beyond Low Earth Orbit and transfer the routine travel to Earth orbit to American companies, as they become proven ready, safe, and certified.

I applaud your continued bipartisan support. I also applaud the people at NASA and in industry who work diligently every day to make these and other important space programs successful.

This year, we are celebrating the 50th Anniversary of the Apollo Missions, with the anniversary of Apollo 11 just this past July. Numerous lessons from the Apollo, Space Shuttle, Space Station and Exploration Programs come to mind that should be heeded as we prepare to return explorers to deep space, first to the Moon and then to Mars.

Part of the discussion today will be about the current status of these exploration programs. I know that they are striving to succeed, and believe they must succeed. I will leave the exact status to NASA, representing the programs.

In my written testimony I will provide:

Part-1 a brief history of how SLS and Orion came to be designed based on goals, objectives, requirements and constraints. I will describe what they were designed to do.

Part-2 my views on the current NASA architecture and the roles of SLS and Orion.

Part-3 given the Exploration Program status, some views on potential improvements in the management approach of these programs.

All of these views are my own.

Part 1

How the Space Launch System and Orion and Come to Be Designed Based on Goals, Objectives, Requirements and Constraints

With the discussions that revolve around the Space Launch System, it is helpful to understand how and why it came to be. This is intended to be a discussion on how this launch vehicle was programmatically and technically shaped by space policy, mission objectives, the technical requirements, schedule and budget, and the realities of the assets and technical capabilities of NASA and the U.S. space industry. My direct experience in Moon and Mars human exploration planning and trade studies has spanned 30 years of participating in, leading, or being responsible for many, if not most of these efforts for human exploration beyond Earth orbit. I will focus on the work accomplished in this era leading up to the SLS and Orion.

It is best to start the discussion by defining what missions are to be addressed and how those drive requirements and what capabilities are needed.

Driving Factors in Development of Requirements

Space Policy

Space Policy sets the framework for what is planned. It has been based largely on a desire for U.S. leadership and a desire for knowledge. These goals can be augmented by desires to reach particular destinations and implementation approaches. The actual implementation is generally shaped by physics and what is practical.

In 1989 on the 20th anniversary of Apollo 11 President George H. W. Bush gave a speech on the steps of the Smithsonian Air and Space Museum. He set the human space policy for returning to the Moon- "Back to stay," and a "Manned Mission to Mars." This began what came to be known as the "Space Exploration Initiative." There have been updates to space policy since that time, including President George W. Bush's "Vision for Space Exploration" in 2004, the NASA Authorization Act of 2005, the cancellation of the Constellation Program under President Obama, and the Authorization Act of 2010. All of these had an effect on the ultimate design of today's Space Launch System. Now we have directives from President Trump and his Administration.

In response to high level guidance there have been numerous NASA agency-wide and independent studies to define the missions and the architecture of space vehicles and infrastructure needed to achieve the goals of human space exploration. These efforts have contributed to the rationale and requirements for the Space Launch System. Requirements included not only those for lift performance, but also other factors such as payload size, safety and reliability. The policy of course continues to evolve in terms of how and when the SLS and human exploration end goals will be accomplished.

Factors Influencing Design- Driving to Requirements

Establishing Objectives for Human Exploration

It is important to develop and weigh what the exploration missions should achieve, before discussing what capabilities to develop. Those objectives define the exploration architecture and scale of operation that will be required. Significant effort over the years has helped to define what those objectives should be. A focused NASA effort in 2006 set out to gather lunar objectives from the broad science/exploration community and all stakeholders. This began with a workshop of these experts and led to a continuing effort with the international space community to refine them. This effort continues through the work of the International Space Exploration Coordination Group (ISECG). The objectives were organized into the themes of Human Civilization, Scientific Knowledge, Exploration Preparation (Mars), Economic Expansion, Global Partnerships, and Education.

As a basis for establishing these objectives, an understanding what is currently known about the Moon is essential. Much had been learned from the Apollo missions and the samples that were returned. Evolving instrumentation technology has led to new discoveries from these incredible samples. In 1994, long after Apollo, the Clementine mission flew to lunar orbit with its instruments, and from the data scientists discovered the potential for water-ice in the permanently dark craters in the Polar Regions. All of the information gathered at this point from the Apollo and Clementine missions led to many new objectives to shape exploration of the Moon. These included many scientific objectives to learn more about the Moon, its history and potential resources. This lunar history is of particular interest, because it is shared with Earth's due to the Moon's close proximity. The Moon has no wind or water to erode the historic evidence as they do on Earth. This provides the opportunity to investigate billions of years of exposure to the Sun's solar wind, meteor impact history and other phenomena. For example, the meteor/meteorite impacts that caused many lunar craters indicate a similar experience witnessed by nearby Earth. But here on Earth the history is largely eroded away. The potential for being able to use water-ice and other resources has added to significant interest in the Moon. Much more detailed data and mapping of other lunar resources has been provided by the Lunar Reconnaissance Orbiter (LRO) and the Lunar Crater Observation and Sensing Satellite LCROSS, which were launched together in 2009. LRO has also provided significantly enhanced surface imaging and mapping that have contributed to better understanding of the Moon's features and provides important data to enable the effectiveness of human and robotic missions. LCROSS impacted one of the Moon's polar craters and measured resources in the plume that was produced by the impact. LRO and LCROSS were specifically planned and funded to prepare for renewed human exploration of the Moon. The Gravity Recovery and Interior Laboratory (GRAIL) mission(s), launched in 2011, have provided the valuable information on the internal makeup of the Moon and its effects on the irregularity of the gravity field. This information is of scientific interest, but also helps to plan more stable orbits around the Moon.

Another important lunar objective is to gain experience in operating on another planetary body in preparing for human exploration of Mars. Yet another objective is the importance of working with international agencies and industry in furthering relationships and US leadership in space. Details of the possibilities for exploring the Moon can be found in the works of the late Paul Spudis and literature of many others who continue studying the Moon and learning from available evidence.

Mars has long been of exceptionally high interest as the planet most like our own. NASA has sent numerous successful spacecraft to land on and orbit Mars. Scientists have learned that it once had running water and had more of an atmosphere than it does today. The data from Mars missions has led scientists to believe there is still water under the surface that could possibly support life. As a result, the development of Mars objectives has been actively pursued for years. There have been incredible discoveries and research based on the robotic Mars missions. There has also been significant work in studying the available resources on Mars and how the water and Carbon Dioxide atmosphere can be utilized to enable/enhance Mars human missions in the future. There is a large body of publicly available work that can be found to gain a more detailed understanding of the potential for further exploration of Mars.

This provides a minute peek at what has driven objectives for human exploration of the Moon and Mars. The intent has always been to reasonably achieve more than "Flags and Footprints" missions.

Defining Requirements for Capabilities to Achieve Objectives

The exploration and science objectives have driven many, many trade studies across the space community over the last 30 years for what is needed in the way of exploration capabilities. They have helped define the scale of operations, mission design and the necessary infrastructure. Objectives have led to the priority of landing sites, which in turn define the lighting, thermal, dust, and radiation environments. These environments form part of the requirements for the surface systems. Examples of needed capabilities include launch vehicles, in-space vehicles, landers, ascent vehicles, habitats for astronauts, rovers, power and thermal systems, science experiments, and potentially mining and resource extraction systems. These integrated studies included developing relatively detailed conceptual designs for each of the elements to understand their mass and sizing. A major part of these studies was also to identify enabling technologies to minimize mission masses and complexity, which seriously affect how much has to be launched from Earth. This relates directly to the overall cost for exploration missions.

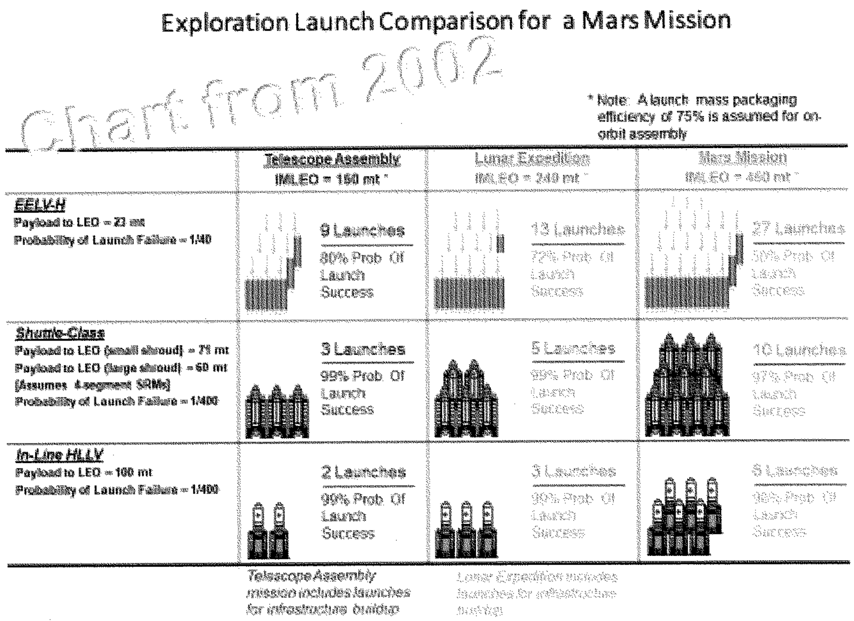
Defining an effective exploration architecture, complete with hardware concepts based on the most practical, but enabling technologies leads to sizing of these architecture components in terms of mass and size. This information drives the requirements for the launch vehicle(s) that have to launch them from Earth. They lead to a definition of the needed capacity in terms of payload diameter and volume in addition to lift performance. Reliability, probability of mission success, and crew safety are also major factors in the definition of the primary launch vehicle(s), numbers of launches per mission, and launch frequency.

Result- Basic Heavy Lift Vehicle Requirements

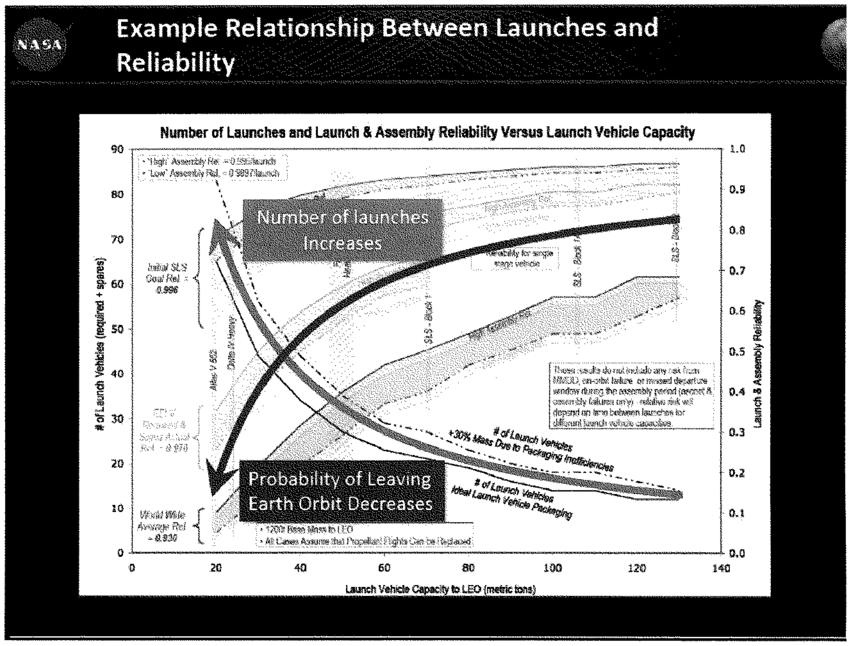
The **sizes and masses** of each of the space infrastructure elements that must be launched from Earth drive the performance requirements of the primary launch vehicle. Studies that ultimately led to the Space Launch System included both the Moon and Mars as destinations for human missions.

Either and/or both destinations led to the same conclusion. Example- In terms of lifting the mass needed for a single crewed mission to Mars, it would take a non-conservative estimation of six to seven 100+ metric ton launch vehicles. That is assuming advanced technologies for in-space propulsion, structures, aero-braking at Mars, life support systems and others. The major elements to be launched are a surface habitat, a lander/ascent vehicle, a transit habitat and systems for the crew, an in-space propulsion system and other necessary surface systems to enable the mission. In addition significant amounts of fuel are needed for the orbit transfers between the Earth and Mars, landing and ascent at Mars.

Over the years, it has been suggested many times by people inside and outside NASA that existing Evolved, Expendable Launch Vehicles (EELVs) could provide the launch capability rather than build a big new rocket. This would be a fortunate solution if it were realistic. Unfortunately thorough studies showed that it is not, because it would take tens of launches, approximately 27 or more EELV (assuming 23 MT to orbit) launches to lift the same amount of mass as the 6 to 7+ heavy lift (100+ MT) vehicles. Complications in planning to these performance numbers occur because of inefficiencies in packaging the flight elements/payloads. It is not always possible to effectively use the entire lift capacity, because of packaging inefficiency. Breaking designs down to fit into smaller launch vehicles, creates the need for complex and heavy interfaces to join the components during assembly. These interfaces include complex latches, electrical and fluid connections. The average packaging efficiency is about 70 to 75% which compounds the problem of numerous launches. For a mission to Mars, a large part of the cargo is fuel to get there and back. Cryogenic fuel boil-off while loitering in space and assembling the mission components also leads to more fuel launches. This points to one of the important technologies that will be needed- cryogenic fuel management and transfer. The following chart is only illustrative of the issue as mission numbers and launch probabilities have evolved.



With increasing numbers of launches, the risk of mission success decreases statistically due to the probability of a launch failure. The reduction in the probability of mission success decreases dramatically as the number of launches (and critical operations) per mission increases.



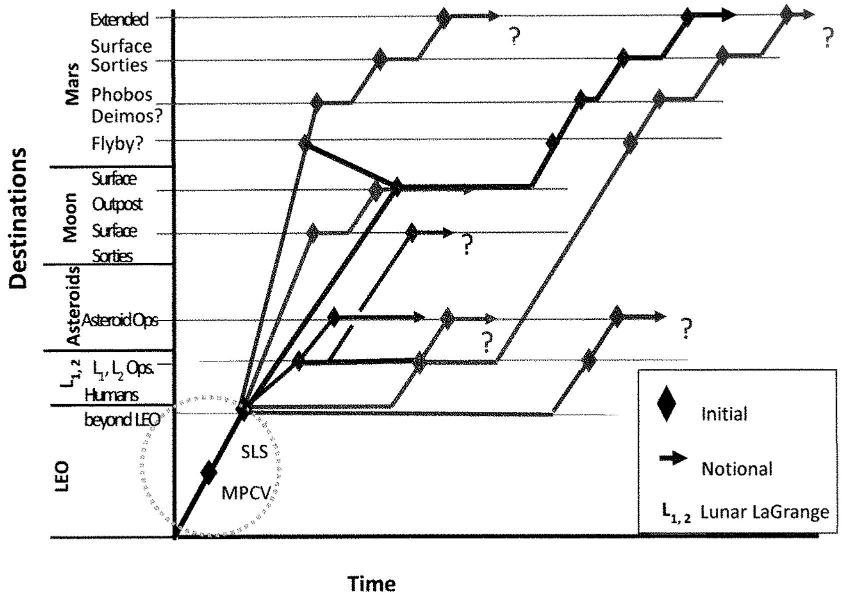
The number of launches for EELV class vehicles was not thought to be practical for a single mission to Mars. Assembly of the International Space Station shared this risk, since it took 40 Shuttle flights to complete. Fortunately, building the Space Station without a mishap on an ISS Shuttle assembly mission was achieved, but there was no room for margin- no backup flight elements. If the Columbia failure had occurred on an assembly flight with a unique flight element, the impact to ISS would have been severe. Using 6 to 7 EELVs for launching lunar missions was also thought to be excessive.

The launch mass is only one part of the problem to be addressed when sizing a launch vehicle. From the earlier discussion exploration mission components are sized by what the missions are to achieve. Lander sizing must accommodate the various payloads it must transport to the lunar or Mars surface. These include ascent vehicles, surface habitats, rovers, and other surface systems. Payloads, such as landers, human habitat modules, future large space telescopes, and other large in-space vehicle designs are enabled by the diameter and volume of a large payload shroud only possible on a heavy lift vehicle that has a large diameter core stage. For instance, landers for the Moon or Mars benefit from the larger diameter to make them wider than they are tall, lowering the center of gravity. This reduces the possibility of turning over if the landing is on a slope. The diameter and volume aspect of the launch requirement is not often addressed in debates on launch vehicles.

The consideration of mass, volume and diameter along with mission risk probabilities have consistently resulted in the requirement for an SLS class launch vehicle for missions to the Moon and Mars.

Basic Crew Vehicle Requirements

Human Exploration capabilities begin with the heavy lift vehicle as described and a vehicle for transporting the crew into space and returning them safely. There are obviously many specific important requirements for the crew vehicle, such as for life support systems, etc. This vehicle was designed to the requirements for an exploration class vehicle and crew of 4 to 6. Studies have shown that for exploration, the crew vehicle is primarily designed for launch and entry at Earth. In the case of Moon missions the vehicle design can be extended to crew transportation to and from the lunar vicinity because of the relatively short duration, approximately three days one way. For longer mission durations such as to Mars or to asteroids, the crew need more habitable volume, more complex life support and consumables. One of the primary drivers is protecting the crew during entry heating. Entry velocities when returning from the Moon (11M/sec) or Mars (~14 to 17M/sec) are much higher than returning from Earth orbit (7.8 M/sec). Earth entry heating increases drastically with velocity. So the heat shield has to be designed for this heating. Heating for lunar and Mars returns drive the vehicle to a blunt capsule shape and materials that can protect the temperature of the vehicle structure. A winged vehicle for instance is not practical. The Space Shuttle could not have survived at these velocities for example. The stay time in deep space was set at 21 days for this vehicle. Beyond that requires more extensive accommodations and consumables. This is well beyond the support capabilities needed for transfers between Earth and Low Earth Orbit (LEO)/ ISS. The propulsive needs of a deep space crew vehicle are also more than what is required for LEO. It must provide the propulsion for orbit transfers and more extensive maneuvers.



Conclusion- Potential Strategies for Mission Architecture Pathways from Earth Begin with Critical Capabilities- A Heavy Lift Vehicle and a Crew Vehicle for Launch and Entry

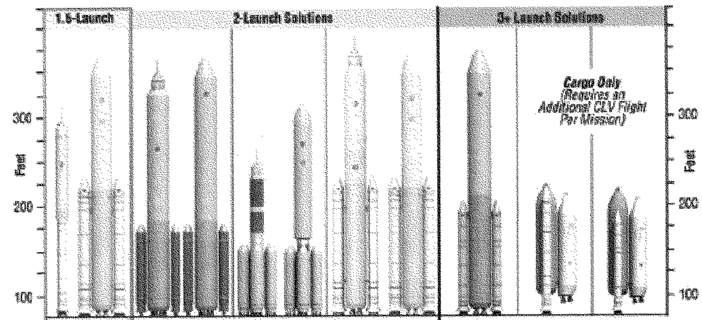
The Congress and Administration through the 2010 Authorization Act; and the Chinese and Russians, as reflected in announcements of their intentions, have recognized the need for heavy lift. For the reasons discussed, sustainable human exploration beyond Earth orbit is not practical without heavy lift of 100 to 130 metric tons lift capability to orbit and large payload volumes. It has been a requirement for those have seriously looked at all aspects of design practicality and mission risk. This level of launch capability and operations is not beyond reason. The Space Shuttle launch system launched the Orbiter and its payload into orbit, the total being on the order of 100 MT. Launches occurred several times a year. This launch capacity is something that we have accepted as a norm and has been necessary for human space flight.

Continuing the Path Leading to the SLS Design

The Vision for Space Exploration (VSE) - Update to the Analysis

President George W. Bush announced the Vision for Space Exploration, on January 14, 2004. This vision set a direction for "a sustained and affordable human and robotic program to explore the solar system and beyond." It set the path for human exploration to the Moon and Mars "and beyond." It also directed NASA to advance technologies to support this vision and promote international and commercial participation. For the first time, since the Apollo Program, NASA was given a significant budget to pursue development of the flight elements for human space exploration to the Moon and Mars. This direction ultimately led to an in depth and broadly based study known as ESAS- Exploration Systems Architecture Study. There were hundreds of NASA employees from across NASA with a core team at NASA HQ studying and comparing hundreds of combinations of vehicles to satisfy basic requirements. The team recommended the designs that would enter development.

Two launch vehicles were chosen, one for crew launch and one for cargo launch. The crew launch vehicle was to be developed first to transport crew to and from the ISS, since the retirement of the Space Shuttle was projected at the time for 2010. This new launcher was later named Ares I. It consisted of a solid rocket booster with 4 segments, derived from the Space Shuttle boosters, and a Liquid Hydrogen/Oxygen upper stage with a RS-25 engine derived from the Space Shuttle Main Engine (SSME). The design was chosen to take advantage of heritage designs for quick development, and because the probability for loss of crew was much lower than any competing design. The second vehicle was chosen to satisfy the heavy lift requirement for both lunar and Mars missions. It shared components with Ares I to save development and recurring cost. It was to have 2 five segment boosters, derived from the Shuttle boosters and a liquid Hydrogen/Oxygen core stage with 5 RS-25 engines. It would have an upper stage using two J 2S engines derived from the Saturn V upper stage engines. It was named Ares V. Other configurations were analyzed and compared but did not compare favorably when combined factors of cost, risk and extensibility to Mars missions were considered.



	5 Segment RSRB In-Line with 5 SSME Core - Cargo	Atlas Phase X (8-m Core)	Atlas Phase 3A (5.4-m Core)	5 Segment RSRB In-Line with 4 SSME Core	4 Segment RSRB In-Line with 3 SSME Core	5 Segment RSRB Side-mount with 3 SSME	4 Segment RSRB Side-mount with 3 SSME
Payload to 28.5	106 mT (125 mT w/ upperstage)	95 mT	94 mT	97 mT	74 mT	80 mT	67 mT
Lunar LV DDT&E*	1.00	1.29	.59	.96	.73	.80	.75
CLV+Lunar Crew/Cargo DDT&E (family op)*	1.00 (4 Seg RSRB w/1 SSME)	1.26 (Atlas V)	1.02 (Phase 2)	.96 (4 Seg RSRB w/1 SSME)	.83 (4 Seg RSRB w/1 SSME)	1.03 (5 Seg RSRB w/J2S-LR85)	.85 (4 Seg RSRB w/1 SSME)
Lunar LV Facility DDTE	1.00	1.33	2.25	1.00			
CLV+Lunar Facilities Cost	1.00	1.12	1.56	1.00			
Lunar LV Average Cost/Flight*	1.00	1.08	1.19	.87	.78	1.13**	1.13**
LOM – Cargo (mean)	1 in 124	1 in 71	1 in 88	1 in 133	1 in 176	1 in 172	1 in 173
LOC (mean)	1 in 2,021	1 in 535	1 in 612	1 in 915	1 in 1,170	N/A	N/A

* All cost estimates include reserves (20% for DDT&E, 10% for Operations), Government oversight/full cost; Average cost/flight based on 6 launches per year.
** Production costs are higher than in-line due to production of separate side-mount cargo carrier

Table from the ESAS report.

After ESAS was completed and the Constellation Program was set up, design studies continued to increase the fidelity of performance, cost, risk, mass of vehicles, etc. Reference designs evolved as a part of this work and as additional factors came into play. The Orion crew vehicle diameter was changed from 5.5 meters to 5 meters. The Ares I first stage was changed to a five segment booster for increased performance. The Ares-1 liquid Hydrogen/ Liquid Oxygen upper stage engine was changed from an RS-25 to a J 2S and be common with the Ares V upper stage engines. Although the RS-25 has been demonstrated to be a reliable in engine in the Shuttle Program, it had never been qualified to be started at altitude as an upper stage engine. The J 2S had been designed as an upper stage engine. The Ares-I upper stage engine would then be common with the Ares V, saving further development cost. This engine was renamed the J 2X engine.

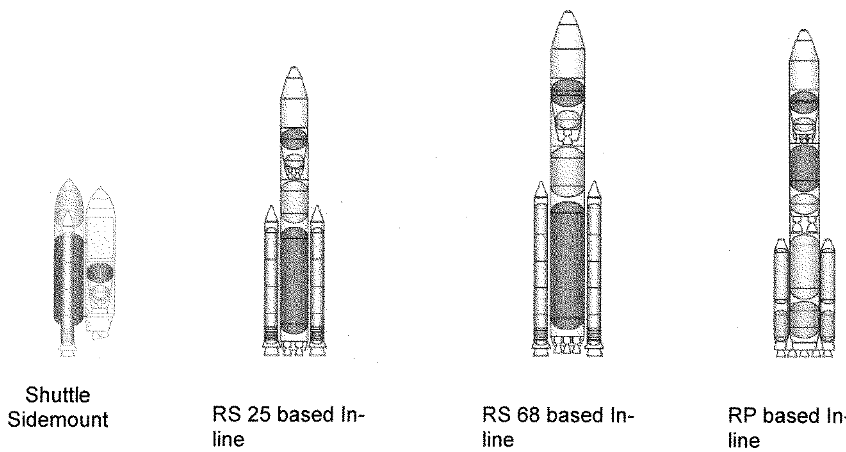
Over time studies led to the adoption of an Ares V core stage using the Liquid Oxygen/ Liquid Hydrogen RS-68 engine from the Delta 4. The RS 68 was in production and had much more modern manufacturing technology than the RS 25. Using it would make it common with the Delta, potentially saving unit costs. The down side was that the RS 68 had features that would have to be redesigned to human rate it. It also was lower efficiency than the RS 25 and would require a 33 meter diameter vs. 27.5 meter for the RS 25 core stage to hold the additional fuel that would be required. The stage could not be stretched, because the height of the hydrogen tank was constrained by the structure for the forward attach point of the 5 segment solid boosters. The additional diameter would also negate use of Space Shuttle heritage ground equipment. Still, the RS 68 solution was attractive because of the engine manufacturing efficiencies.

As the newest initiative in human spaceflight at NASA and being early in its development (not operational), the Exploration Directorate had to pay for a few large unanticipated human space flight bills, such as extra Space Shuttle flights. There was also a full year continuing resolution in 2007 that cost the directorate about $577M.

Change in Administrations from President Bush to President Obama- Update to the Exploration Approach

In the budget that was released in February 2009, the Exploration budget was further reduced in the out years, almost exactly the amount of the wedge for lunar developments for Ares V and a lunar lander. Ares I and Orion still had funding and for 2009 and 2010 that was actually higher than proposed the prior year. This budget was not challenged by Congress as they waited to see what policy the Obama Administration would come out with. In the summer of 2009 the Administration was announcing the initiation of an independent review of "ongoing U.S. human space flight development activities as well as alternatives to ensure that the Nation is pursuing the best solution for future human space flight." It was known as the Augustine Committee review. The committee looked at 5 mission options within the projected budget. Not surprisingly, since the recently released budget runout had been reduced from prior projections, finding an exploration path was not possible. From their report "Seeking a Human Space Flight Program Worthy of a Great Nation," they stated "Human exploration beyond Earth Orbit is not viable under the FY 2010 budget guideline." "Meaningful exploration is possible under a less-constrained budget, increasing annual expenditures by approximately $3B in real purchasing power beyond the FY 2010 budget guidance."

The Augustine review and surrounding discussions began to indicate that there was pressure to move towards commercial crew transportation and away from Ares I. There was growing interest in the heavy lift vehicle needed for exploration missions. There were different camps with competing ideas of what it should be even though there was a baseline for Ares IV/V. The Exploration Systems Mission Directorate (ESMD) and Space Operations Mission Directorate (SOMD) decided to initiate a broad study comparing all of the viable approaches with experts from across the human space flight field centers. A special effort was made to pick the leadership of the team and set the ground rules to make sure that the concepts were compared on an apples to apples basis. These were thorough studies that compared launch capabilities for all foreseeable human mission destinations, including the Moon, asteroids, Lagrange points and Mars. The concepts were evaluated comparing launch performance, safety and risk, reliability, operability, extensibility to all possible human space flight destinations, cost and schedule. Results narrowed the possible solutions to competitive approaches. The shuttle side-mount approach was eliminated as not fully addressing program performance needs for all destinations. The in-line rocket approaches based on RS-25 engines/solid boosters, RS-68 engines/solid boosters and Liquid Oxygen/Kerosene (RP) engines could each accomplish the missions. Each had their pros and cons when comparing the various metrics. The concepts are shown in the following table. NASA studies continued to refine the designs and comparisons between the in-line concepts.



Primary concepts studied in ESMD/SOMD joint study

Cancellation of Constellation Program- February 2010

With the rollout of the President's Budget Request (PBR) in February, 2010, the Administration announced the cancellation of the Constellation Program, including Ares I, Ares V, and associated Ground Systems. The proposed budget replaced the program with increased spending for research and technology, technology flight demonstrations, a hydrocarbon rocket engine technology program, spending on a commercial crew program, and closeout of the Constellation Program.

Within days a letter was written to the NASA administrator signed by 29 members of the House of Representatives warning against terminating Constellation contracts. The letter stated "the Consolidated Appropriations Act for Fiscal Year (FY10) contained bill language prohibiting NASA from terminating current programs which are part of Constellation and also from initiating new programs." This put NASA into a period of maintaining contracts but not starting new tasks. Contracts were maintained with very constrained funding levels to prepare for the most constraining budget outcome between the policy proposed in the President's Budget Request and the intent of Congress. Studies continued on heavy lift vehicle options.

NASA Authorization act of 2010

In October, 2010, the 2010 NASA Authorization Act was passed. This Act established the policy of building the Space Launch System and a Multi-Purpose Crew Vehicle (MPCV) for Exploration missions beyond Low Earth Orbit. The Act specified the initial SLS performance was to be between 70 and 100 MT to low Earth orbit with the ultimate capability to be at least 130 MT. The 2010 Act also directed NASA to utilize and modify existing contracts to the "extent practicable" to reduce termination costs.

Decisions for SLS

NASA immediately began work on a program formulation plan to define final configurations for SLS and the Multi-Purpose Crew Vehicle (Orion) and develop acquisition plans. SLS planning was based on the ESMD/SOMD joint study results at that point. The decision would be between in-line concepts- a LOX/RP first stage, an RS-25/solid rocket based first stage, or an RS-68/solid rocket based first stage. A Requirements Analysis Cycle was begun to look for ways to improve affordability of the design. A Broad Area Announcement (BAA) was released to industry- requesting ideas and innovation from the aerospace community, and look for onramps of new capabilities. Thirteen companies were funded through the BAA to provide NASA recommendations. Acquisition planning was begun to determine the best path forward for contracts.

Important parameters for SLS were essentially the same as those from past studies. The basic exploration requirements had to be addressed, including lift capability, payload volume and diameter, which was consistent with the direction in the NASA 2010 Authorization Act. As before safety and risk, reliability, operability, extensibility to potential human space flight deep space destinations, cost and schedule were all important considerations.

Schedule differences between designs were very important. The programs were obviously vulnerable given the recent history, so the most expeditious development schedule was a major factor. Acquisition strategies, including the potential use of current contracts and/or assets was a major factor in schedule.

The budget was still very constrained. Budget became the gate for the ultimate decision.

There were additional factors that had to be considered along with the rationale and requirements for the launch vehicle. What was the state of propulsion technology? What was the effect of vectoring the government/industry work force? What was the effect on the space industrial base? These were not trivial factors. It was important to consider the state of investments in large launch vehicle capabilities and components, the state of technology, reliability, and cost compared with what could be accomplished with new designs and potentially newer technologies. It was important to understand the current state of NASA and aerospace industry expertise and manufacturing capabilities for the potential alternatives. These aerospace industry capabilities have been driven by long-past programmatic decisions such as cancellation of the Saturn program with its huge kerosene first-stage engines, the capabilities from the development of Evolved Expendable Launch Vehicles (EELVs) and the development and long-term reliance on the Space Shuttle Liquid Hydrogen engines and solid rocket boosters.

In evaluating the LOX/RP (kerosene) option, history showed that the U.S. had invested very little in large RP engine technology and had no production since the Space Shuttle design decision was made 40 years earlier. NASA had invested in development of the large liquid Hydrogen/liquid Oxygen Shuttle Main Engine years prior to the Shuttle decision. At that time NASA wanted to use a booster employing the large Saturn V RP F-1 engine for the Shuttle. OMB showed that using large solid rocket boosters would be more cost effective than the F-1 booster, since the Titan IV was also using large solid boosters at the time. There would be cost savings in the shared technology and infrastructure. The decision was to employ solid boosters for the Space Shuttle. The development time and cost to design and build a new large RP engine for SLS would not fit the budget and schedule.

In comparing the RS-68 and RS 25 based versions, the RS 68 was attractive, because of its advanced manufacturing techniques. However as stated earlier, there were design fixes that were needed to human rate it and the tank design would be a larger diameter and more expensive than the RS-25 based design. The tank diameter was driven by the difference in engine efficiency, the RS 25 being more efficient. The tank diameter for the RS 25 was the same as the Shuttle external tank, and there were savings in ground handling equipment. The Shuttle main engine (RS 25) was obviously human rated, and it was still state of the art in LOX/Hydrogen engine performance- near theoretical limits. The engine design had been evolved throughout the Shuttle program to fix problems and improve reliability. The manufacturing technology would have to be improved in the future. The other major benefit was that there was an existing inventory of Shuttle engines that would be available when the Shuttle was retired. Any near term cost would be minimal.

The solid booster technology and much of the hardware for many flights came directly from the Shuttle Program. A five segment booster had already been ground tested as part of the Constellation Program. Improvements had been made over its life and during Constellation. It was a low risk asset.

As stated earlier the budget was a gate to pass. There was little money for new development in the SLS Program. Development money had to be spent on the Core Stage, consisting of the main Hydrogen and Oxygen tanks, the main propulsion system (highly complex controls plumbing, valves, instrumentation, etc.) and integration of the main engines. There were enough existing RS 25 engines from the Shuttle Program for a number of flights. Solid booster final design and testing would be completed. The RS 25 based design was the lowest in near term cost. The return on investment for the RS 68 was better long term, but the payoff was many years out. The decision was to develop the RS 25 based core stage with the five segment solid rocket boosters.

At the time of the decision the upper stage for the SLS would be based on the Ares I upper stage using the J2X, which was under contract. The stage size would be increased to reach the 100 to 130 MT SLS lift capability. A decision was made to use the Delta IV upper stage (renamed Interim Cryogenic Propulsion Stage-ICPS) for the first SLS test flight.

The Orion Design Decision

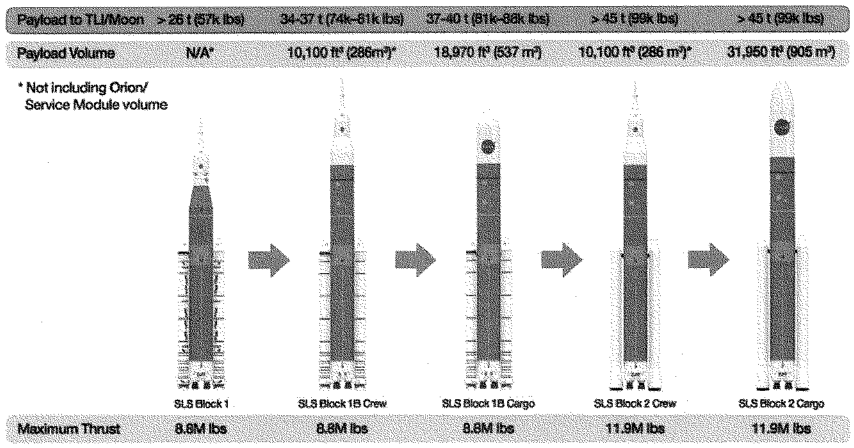
Orion went through a decision process equivalent to the SLS process, and decisions were made at the NASA Administrator level. The decision was to continue with the Orion design, which was ongoing and addressed all of the deep space requirements. Commercial Crew vehicles, which were just getting underway, did not have the requirement to protect for deep space Earth entry velocities or mission duration that Orion did. The deep space mission also required more fuel in the service module for deep space propulsion and maneuvers. This drove the combination of abort systems and service modules to different design concepts.

Summary

All of the factors; space policy, mission objectives, performance and safety requirements, and space industrial base expertise and capabilities were traded and weighed against available budget, which was the biggest constraint, and the objective of having near term accomplishments- schedule.

Resulting SLS Design Implementation

The first stage utilizing the RS 25 and five segment solids is nearing completion and test flight hardware is being completed. The upper stage concept has changed to use the RL 10 engine. This stage is called the Exploration Upper stage. The RL 10 is a proven engine with many years of service. This combination can deliver 100 MT to Low Earth Orbit and is responsive to the requirements for human exploration of the Moon and Mars. It is also responsive to direction in the 2010 NASA Authorization Act for the lower end of the performance range (100- 130 MT). It is shown in the figure below as SLS Block IB for crew and cargo versions.



Part 2-

Views on Use of the SLS in the Current NASA Architecture

The role of the Orion capsule is used in a standard way based on deep space requirements. Therefore this discussion is based on SLS utilization in the architecture, once again, starting with top level requirements. The Trump Administration has taken a keen interest in the U.S. role in outer space. These have been reflected in specific directives. The President Trump Space Directives 1, 2 and Pence Policy Statement are most relevant-

Space Directive 1:

“The directive I am signing today will refocus America’s space program on human exploration and discovery,” said President Trump. “It marks a first step in returning American astronauts to the Moon for the first time since 1972, for long-term exploration and use. This time, we will not only plant our flag and leave our footprints -- we will establish a foundation for an eventual mission to Mars, and perhaps someday, to many worlds beyond.”

Space Directive 2:

"The president is committed to ensuring that the federal government gets out of the way and unleashes private enterprise to support the economic success of the United States," White House officials wrote in an SPD-2 fact sheet that was released yesterday.

https://www.whitehouse.gov/presidential-actions/space-policy-directive-2-streamlining-regulations-commercial-use-space/

Space Directive 3: Space Traffic Management

https://www.whitehouse.gov/presidential-actions/space-policy-directive-3-national-space-traffic-management-policy/

Space Directive 4: **Establishing Space Force**

https://spacepolicyonline.com/news/text-of-space-policy-directive-4-spd-4-establishing-a-u-s-space-force/

Pence announcement of lunar Landing by 2024

https://www.space.com/us-astronauts-moon-return-by-2024.html

Although there is a specific interest in commercialization of space, those desires do not change physics and for the time being run counter to the overriding hard requirement of landing a crew on the Moon by 2024. The NASA concept of operations is shown in the figure below. It is a very complex combination of vehicles flight hardware and operations to put a crew on the Moon by 2024. Only Orion and SLS are in hardware development. All of the other flight elements have only very recently been awarded or are just now being solicited by NASA. Remember, the hard requirement is to land a crew on the Moon by 2024.

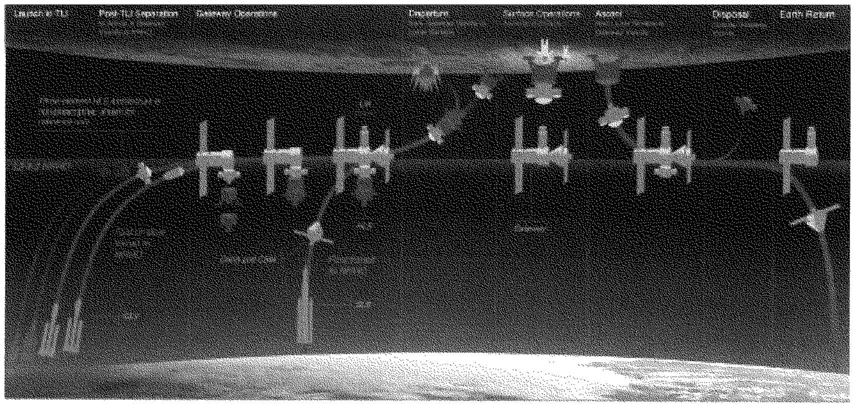


Figure 1 - Generic Concept of Operations for the initial mission capability. The three-element architecture is for reference only and represents one possible approach, hence two of the three elements are shown in grey.

Questions:

1. Fifty years ago NASA flew Apollo 11 on a single rocket with a capsule and a lander. Why does it take numerous flights of small rockets to send two astronauts to the Moon?

2. Isn't NASA in fact building a large rocket- the Space Launch System with a large upper stage (EUS) that could fly the crew to the Moon and back potentially in as little as 2 flights with many fewer complex operations and fewer new spacecraft needing design and development from scratch?

Discussion

NASA is on a contractual path to complete the SLS 1A and the hardware is being built. It is also on the path to design and build the Exploration upper Stage that will provide the SLS 1B lift and volume capability. NASA must also design a cargo shroud for the 1B version

Using an SLS Block 1B Cargo Vehicle, carrying a lunar lander/ascent vehicle, and an SLS Block IA Crew Vehicle, carrying the Orion Crew vehicle and possibly a transfer stage if needed, the United States could send a crew to the Moon and return them safely.

The following is a simplistic comparison of the numbers of developments, launches, and complex in-space operations leading to the combined probability of a successful mission to the Moon for Apollo, the NASA architecture including the Gateway, and a simpler approach taking advantage of SLS capabilities. It uses a probability of .98 for each launch and operation for simplicity.

	Apollo Program	NASA Baseline	Alternative
Developments	(1) Saturn V (2) Apollo (CM + DM) (3) LEM (AE + DE)	SLS (near completion) Orion (near completion) (1) DE (2) AE (3) AETV (4) TE (5) RE (6) PPE (7) MHM (8) GLS	SLS (near completion) Orion (near completion) (1) DE (2) AE
Launches	(1) Saturn V (Co-Manifest)	(1) SLS Block 1 (Orion) (2) CLV (DE) (3) CLV (AE + AETV) (4) CLV (TE) (5) CLV (RE) (6) CLV (PPE) (7) CLV (MHM) (8) CLV (GLS)	(1) SLS Block 1 (Orion) (2) SLS Block 1B (DE+AE)
Mission Operations	(1) Apollo/LEM Mating after launch (2) Apollo/LEM De-mating (3) LEM Landing (4) Ascent Boost (5) Apollo/Ascent Mating (6) LEM Separation/Disposal (7) Apollo Return to Earth	(1) MHM docking with PPE (2) TE docking with MHM (3) DE docking with MHM (4) RE docking with DE (5) Refueling of DE (6) AE docking with MHM (7) AE mating with DE (8) AE/DE mating with TE (9) GLS mating with MHM (10) Orion mating with MHM (11) AE/DE/TE separate from MHM (12) TE staging (13) AE/DE landing (14) AE boost from lunar surface (15) AE docks with MHM (16) Orion separates MHM (17) Orion returns to Earth	(1) Orion mating with DE/AE (2) AE/DE separates from Orion (3) AE/DE landing (4) AE boost from lunar surface (5) AE docks with Orion (6) AE separates from Orion (7) Orion returns to Earth
Probability Analysis	Assumed probability per event 98%		
Developments	3	8	2
Launches	1	8	2
Mission Operations	7	17	7
Total Events	11	33	11
Probability of Mission Success	80%	51%	80%

In viewing recent documentaries of Apollo 11 during the 50th anniversary it reminded me about how much anxious anticipation you have as each critical operation occurs, knowing it can be a mission ending or life threatening event. This can also be seen in robotic missions, recalling the JPL Curiosity Mission and the "Seven Minutes of terror" as the team awaited the signal of the successful Mars landing. Minimizing the number of events can significantly improve the probability of mission success.

In contrast to the SLS approach to the first lunar landing, the NASA architecture uses the SLS only to launch the Orion. It plans to use commercial vehicles to launch the components of the lander and ascent vehicle separately. The lander must then be refueled in space, because of commercial launch vehicle lift limitations. Refueling in space is not a well-developed technology at this point in time for that matter. The lander size will also be constrained to commercial launch vehicle shroud diameters. Without the benefit of defining concepts for the surface hardware based on mission objectives, as described earlier, will this lander have the capacity for all the hardware it will take to the surface over time? Will it be forced to use hypergolic storable fuels because of the launch vehicle constraints? If so. this does not fit the scenario of using commercially provided fuels manufactured on the Moon. The concept seems to consider only the crew transfers for 2024. All of the assembly complexity occurs, because NASA does not use the SLS for what it was designed to do. This adds cost, complexity and mission risk. Taking advantage of the SLS lift and volume capability would allow the Gateway to be deferred to later, when it could help to provide longer mission durations by supporting Orion stay times in orbit. Therefore Gateway would not be on the critical path for 2024.

From a procurement standpoint, it would seem that following through on the SLS and EUS contracts with the addition of a cargo shroud, and focusing on the procurement of a lander/ascent vehicle would have a better chance of making an early lunar landing date rather than betting on the large number of brand new procurements in the current architecture. What is the probability of all of these procurements going well simultaneously? Any one procurement could hold up the entire architecture.

In my view, the SLS solution for early lunar flights is a lower risk solution compared to forcing the current NASA architecture. It has the best chance of meeting the number 1 requirement set by the Administration. There will be time for the rest of the architecture, which will provide opportunities for commercial flights. The launch vehicles can be better suited for flying the intended payloads.

Part 3- Space Exploration Program Performance

The Role of Systems Engineering and Integration in Large Government/NASA Programs

SE&I is a major function in any program, necessary to ensure safety and successful operation of a design and ensure that it satisfies the intended performance. This is particularly true in large space programs where there is little margin for error. SE&I is comprised of a number of functions including engineering analysis across the components of a design- major systems such as power, thermal, structures, mechanical systems, data systems/avionics, life support systems, etc. It is the work that assures all components are compatible and work together according to the overall design in the various environments they have to operate. SE&I efforts establish requirements for performance, safety, reliability, environments, etc., Power/electrical, fluids, data, environmental and mechanical interfaces between flight elements and components are established and documented. Components are designed to those interfaces so the spacecraft functions successfully as a unit when the components are assembled. Through SE&I analysis and testing are defined that will verify that the technical and interface requirements have been met, once designed and built. SE&I assures that the data systems and software will successfully control the vehicle functions over the entire range of intended operational envelopes. Throughout the design process SE&I activities maintain documentation on the risks in the design and in the program as a whole. Analysis and even design changes are authorized to work down these risks. Managing SE&I involves complex decisions to ensure all disputes and negotiations between the systems designers in these areas are resolved and that all are operating to the same baseline. SE&I is also where the detailed integrated schedule is managed and funding allocations are proposed to assure the components of the design come together for assembly and test at the appropriate time. SE&I is a function that should operate across the program, and also at project and component levels to assure that all of these requirements and functions flow down for a successful integrated design. This is but a brief discussion of a very complex programmatic function- SE&I.

Discussion of Program Performance on SLS, Orion, Ground Systems

The recent GAO report in June, 2019 (19-227) "NASA Human Space Exploration – Persistent Delays and Cost Growth Reinforce Concerns over Management of Programs" raises concerning issues. The GAO report focusses on poor reporting of metrics by programs, inadequate program plans/cost baselines and accounting, and award fees not aligned with observed performance. The report talks about the program reporting cost performance against baselines that have reduced content, due to rephasing of work. It talks about identified schedule risks for known work that is not currently scheduled. It also recognizes the contribution of technical problems that arise in these complex programs. And of course the report expresses the concern about program delays due to these and related issues. A closely linked GAO report in October 2017 (18-28) titled "NASA Human Space Exploration – Integration Approach Presents Challenges to Oversight," raises concerns about the NASA Integration approach, including dual roles for oversight organizations. It gives the program credit for cost avoidance for not having a significant Systems Engineering and Integration (SE&I) workforce at the Top Program level (HEOMD/ESD) Successful large programs do. The cost avoidance is quoted as being on the order of $150M when compared with the Constellation Program. But the report goes on to talk about many of the reporting problems listed in the most recent GAO report. It raises concerns about this program level being able to cover all of the reviews and the ability to cover added work as the programs reach test and verification needs coming up with this small SE&I effort. Issues of poor reporting metrics and lack of adequate integrated program/cost plans can be attributed to the lack of an adequate Systems Engineering and Integration level at the top of the program. I have heard what they have described as SE&I "Light". My experience in The Space Shuttle, ISS, and Exploration Programs has been that strong SE&I function is crucial to having a healthy and successful program. Many of the program reporting criticisms and lack of integrated cost and schedule could be alleviated with this function in place. Adequate cost and schedule planning would minimize the risks associated with parallel design and manufacturing and testing. What is worse than poor reporting and metrics is that without a rigorous Systems Engineering and Integration effort, there can be major incompatibilities with the major hardware components, such as hardware interferences and interfaces that don't work. In the current Artemis architecture, there are many interfaces between major components to be built by different companies, i.e., Orion, SLS, Ground Systems, PPE, minihab, Descent Element, Ascent Element, Transfer Element, Logistics Element, Commercial Launch Vehicles, lunar surface systems, robotic arm, etc. Interfaces that must work include structural/mechanical, air, power, thermal, data, fluids; all at compatible conditions.

The lack of a thorough SE&I function is a high risk for the programs, and may well have led to many of the current schedule and cost issues. It may also mean there are more coming without it. Without the oversight/insight at this high level across the program it is difficult to assure consistent working practices and due diligence in resolving inevitable problems, and difficult to ensure that NASA and contractor organizations bring their A-teams to these programs. This function with strong leadership helps to instill the urgency needed in getting the job done on cost and schedule.

In my view this current concern is repeating what occurred during the Space Station Freedom Program, when projects called "Work Packages" had their own prime contractors. There was a Program Office and integration effort at NASA in Reston, Virginia. There was a support contractor for Reston, which had an SE&I support function but was not legally accountable for the integration of the vehicle. The Program Office in Reston had no budget control, because the Work Packages worked for JSC, MSFC and GRC Center Directors, respectively and were paid through the centers by other NASA HQ directorates. The various offices fought. The integration and interface control was dysfunctional, not for lack of trying by a lot of excellent people at Reston. When the redesign of the Space Station occurred during 1993, and the new ISS Program Office was assembled in Houston, there were lingering serious design and interface issues. The management was coalesced, a strong SE&I organization was formed between NASA and a new overall Prime Contractor for ISS. I believe this was all a large factor in the success of ISS. All of the reporting, metrics, and schedules against cost were mandated. Technical problems were worked. Even the Russians were brought on as partners during this time and integrated into the design. Processes were put in place to assure diligence to getting the job done, through strong leadership and creating a strong culture. I recommend that this be done for these programs as soon as possible to fix the problems described in these reports. It will cost money, since they don't have it allocated now, but it will bring order and a successful program. **NASA needs a strong program office, prime contractor, and a skilled SE&I Organization.** It will be said we can't do it now with the 2024 mandate. Over the years it has often been said you never have time to do things right. That is until you find it's the only way to get it done.

It is possible to use award fees as described in the GAO report, but the NASA team has to do their part and be a part of a strong team described above. For example, if NASA owes direction to contractors and doesn't provide it on time, work does not get done. It's not fair to ding contractors for it. Much of the integration work in these programs has been taken on by NASA organizations and their support contractors. If NASA does not produce its deliverables according to the program schedule, the contractors have a valid claim that they cannot proceed. If NASA does not show excellence on their side and show leadership, it's hard to blame the contractors. These issues are another reason for having a prime contractor that can be held accountable. Award fee periods are much clearer under these circumstances.

My Management Lessons

The following are key program management lessons I take away from the Apollo, Space Shuttle, Space Station, and Exploration Programs. It's not an exhaustive list.

1. Prioritize the highest requirements above desires. NASA has been given a hard goal to achieve a lunar landing by 2024. Other top priorities have to include safety and risk, cost and schedule. Basic safety requirements should provide the check and balance for the others.

2. Define key mission objectives to drive sustainability, mission design, scale of operation, mission architecture and sizing of vehicles and capabilities. Develop a long term plan. It should be flexible for what is learned and as new technologies and capabilities emerge.

3. Don't design in dead ends. Developments should all contribute to downstream goals for the Moon, Mars and beyond.

4. Strive for simplicity in design and operations to reduce mission risk. It will still be more complicated than would be desired.

5. Organize to execute the program efficiently and effectively. Implement a strong Systems Engineering and Integration function. Streamline program processes and decision making.

6. Strive to develop an A-team at NASA and industry partners. Operate the program with urgency- not business as usual and not at the expense of safety.

7. Streamline requirements for all programs, but maintain basic safety requirements

Summary

I have provided a brief history of the Current SLS and Orion designs and why they are important to human spaceflight based on their requirements and capabilities. These capabilities were designed for both the Moon and Mars Missions. The programs have certainly had issues of various kinds during their development thus far. There are management approaches and remedies that can improve the path forward. It includes a lot of hard work and dedication. These programs have great potential for inspiring missions. NASA should take advantage of the progress made in these programs and across the board in space flight. NASA still needs to develop a long term plan that will guide the mission architecture and missions. I have testified on this subject before with the following recommendations:

- Missions should address science, exploration, commerce, geopolitical and other objectives to maximize the potential for great achievements and discoveries. It is not enough to describe vehicles and how we are technically going to perform missions. Well-vetted objectives provide the important rationale for the exploration plan and help guide specific missions.
- International collaboration is essential in planning, development of hardware, and participation in missions and operations. We have learned through the International Space Station (ISS) Program, and science missions the value of international collaboration on many levels. Collaboration provides the opportunity for pooling resources to accomplish more than any one country can on its own. Collaboration is a rewarding experience among nations and is a positive influence in international relationships. The International Space Exploration Coordination Group (ISECG) continues to work on exploration objectives, roadmaps and planning for future human space exploration. NASA has provided the leadership in these relationships and I believe must continue to do so. The critical geopolitical considerations of our time strongly mandate that the United States step up to the responsibilities of that leadership role and guide the proper use of space. What's more, these nations look to the U.S. and NASA for this leadership.
- The needed capabilities and technologies should be developed incrementally, paced with available budgets. A long-term plan will help define the specific capabilities that are needed and will provide the priorities and phasing of these developments. Without a plan, capabilities developed can miss the mark and fall short of what will be needed. Other NASA programs, international agencies and companies, industry, academia, DOD, and other agencies and their programs can be leveraged to maximize progress.
- Every mission and capability developed should contribute to long-term exploration needs and objectives. To the degree possible, each flight element, including in-space habitat modules, landers, rovers, space suits, power systems, and others should be developed for multiple use. This begins with the foundation of International Space Station (ISS) testing and research, routine transportation

to Low Earth Orbit, and the development of the Space Launch System (SLS) heavy lift rocket and Orion Multi-Purpose Crew Vehicle (MPCV).

- Exploration capabilities should be made available for commercial and other interests to further the utilization of space. As NASA develops capabilities to explore farther and farther from Earth, other interested parties may find advantage in using these capabilities at destinations in space, where NASA has paved the way.
- The long-term plan should be adaptable based on discoveries and budget realities. With it we can envision a logical sequence of missions based on known objectives. However, by the nature of exploration, missions will lead to discoveries that may change priorities. The plan should be adaptable based on these discoveries. A perfect example of this idea in practice is the NASA Mars Science Program. Roadmaps with specific sets of objectives and missions have been developed for the last two decades. Discoveries have been prevalent in this program, and the plan has been adjusted to make the most of every upcoming mission.
- Constant progress should be made towards the long term goal of landing people on Mars to explore this planet. Mars is globally accepted as an ultimate human space flight goal based on the fact that it is the planet most like our own and may hold evidence of past or present life. It is habitable with known systems, and can be reached within foreseeable technological capabilities.

Once again, thank you for inviting me to give my personal views. I also want to thank this committee and your staff for your continued bipartisan support for human space flight.

I welcome your questions.

Doug Cooke

Short Biography - Douglas R. Cooke

Doug Cooke is an aerospace consultant with over 46 years' experience in human space flight programs, advising clients on program strategies, program management, contract proposal development, strategic planning and technical matters. In 2011 Doug Cooke retired as Associate Administrator for NASA's Exploration Systems Mission Directorate (ESMD), having been assigned to this position in 2008. As Associate Administrator, he was responsible for the Constellation, Space Launch System (SLS), the Orion crew vehicle, Ground Systems Development and Operations, Lunar Reconnaissance Orbiter, Lunar Crater Observation and Sensing Satellite, Commercial Cargo and Crew, Human Research and Exploration Technology Programs. The development programs were responsible for design and manufacture of flight vehicles and hardware systems for human exploration into deep space, including the Moon, Near Earth Asteroids, Mars and its moons and other destinations. The research programs developed critical technologies, new capabilities, and human research to support future human spacecraft and exploration missions. Responsibilities also included partnering with industry to develop commercial vehicles for cargo and crew transportation to and from low Earth orbit and the International Space Station. In his last year at NASA, Doug Cooke led the directorate and program teams in the analysis, designs and establishment of the Orion Multipurpose Crew Vehicle and the Space Launch System. He personally presented the proposals at agency level meetings, where the administrator approved these programs.

Doug Cooke has 38 years of unique experience at NASA, with 32 years at Johnson Space Center and 6 at NASA Headquarters. He held significant responsibilities during critical periods of the Space Shuttle, Space Station and Exploration Programs, including top management positions in all three programs.

Doug Cooke's first major challenge began in 1975 when he was tasked with defining and implementing the entry aerodynamic flight test program for the Space Shuttle. He led this effort through the Approach and Landing Tests in 1977, and initial orbital flights of the Space Shuttle beginning in 1981 through 1984, opening flight constraints to meet entry design specifications.

Doug Cooke led the Analysis Office when the Space Station Program Office was first organized in 1984 at the Johnson Space Center. He led the work that defined the Space Station configuration, many of its design details, technical attributes and requirements.

Following the Space Shuttle Challenger accident, Doug Cooke was assigned to the Space Shuttle Program Office. He helped lead a Civil Service and contractor team to provide the system engineering and integration function that resulted in the return of the Space Shuttle to flight on September 29, 1988. He reached the position of Deputy Manager of the Space Shuttle Engineering Integration Office.

Doug Cooke has played a pivotal role in planning for human space exploration into deep space beginning in 1989. He helped to lead a NASA team that produced the "90 Day Study" on lunar and Mars exploration. He was subsequently assigned to the Synthesis Group led by Lt. General Tom Stafford, Gemini and Apollo Astronaut. The team produced a report for the White House entitled "America at the Threshold: America's Space Exploration Initiative." Doug Cooke was selected to be the Manager of the Exploration Programs Office at JSC, where he initiated and led NASA agency-wide studies for the human return to the Moon, and exploration of Mars.

In March of 1993, the agency undertook the redesign of Space Station Freedom. Doug Cooke was assigned the responsibility of leading the engineering and technical aspects of the redesign. He was subsequently chosen to serve in the Space Station Program Office as Vehicle Manager, leading and managing the design, hardware development and systems engineering and integration for the International Space Station. From April to December of 1996, He served as Deputy Manager of the Space Station Program Office.

In 1996, strategic emphasis was again placed on NASA planning for human exploration beyond Low Earth Orbit. Doug Cooke served as manager for the Advanced Development Office at the Johnson Space Center. He provided NASA leadership for the planning of human missions beyond Earth orbit; including the Moon, Mars, libration points, and asteroids. This team developed integrated human and robotic mission objectives, defined investment strategies for exploration technologies, and managed NASA exploration mission architecture analyses. He was detailed to NASA headquarters during portions of this period to contribute to headquarters level strategies for human exploration.

In 2003, Doug Cooke served as NASA technical advisor to the Space Shuttle Columbia Accident Investigation Board from the time of the accident to the publishing of the report. He made significant contributions to forensic analysis of the Columbia debris and to the education of the Investigation Board in various aspects of the Shuttle design, program, operations and interpretation of investigation data.

Doug Cooke served as Deputy Associate Administrator for the Exploration Systems Mission Directorate, NASA Headquarters, from 2004 until 2008. In 2008 he became Associate Administrator. He made significant contributions to the structuring of its human exploration programs, defining the program content, budget planning and providing technical and programmatic leadership. Doug Cooke also led the efforts to define long term NASA field center assignments for hardware development and operational responsibilities. He was the Source Selection Authority for the major exploration contract competitions. In this role he successfully selected the companies who have been on contract for SLS, Orion and Commercial Cargo. He initiated and led the team of international space agencies in development of the Global Exploration Strategy activity, which resulted in the establishment of the International Space Exploration Coordination Group and the release of the Global Exploration Roadmap.

Doug Cooke's many awards include the SES Presidential Distinguished Rank Award, the SES Presidential Meritorious Rank Award, NASA Distinguished Service Medal, two NASA Exceptional Achievement Medals, the NASA Outstanding Leadership Medal, the NASA Exceptional Service Medal, two JSC Certificates of Commendation, the first

Texas A&M Outstanding Aerospace Engineer Alumni Award, the Space Transportation Association Lifetime Achievement Award, the 2017 Werner Von Braun Astronautics Engineer Award. Most recently, in 2018, he was awarded the Texas A&M Distinguished Aerospace Engineering Alumni Award. Doug Cooke is a graduate of Texas A&M University with a Bachelor of Science degree in Aerospace Engineering.

Chairwoman HORN. Thank you, Mr. Cooke. We'll now begin with questions. As you could tell, we have many questions. We're all on the same page, I think, clearly on both sides of the aisle here about supporting a strong exploration program and the need to ensure that we do it right and sustainably. So I'm going to start with a few questions, Mr. Bowersox, for you. And I'm going to ask you a series of questions, and we'll go through them pretty quickly and then we'll come to some more.

So the first question, when will NASA determine a new launch readiness date for EM–1, and what are the risks of continuing to delay announcement of a new launch date?

Mr. BOWERSOX. Well, right after naming a permanent Associate Administrator, we expect within a month or two that person would have time to come up with the date that they can be ready to commit to Congress on.

Now, I would like to assure you we've got a schedule we're working internally, but it's what we call a manage to schedule, right? It's a best-case schedule. The reason we want to give a new person a chance to take a look at what we're thinking about is there are some uncertainties in there that, before they commit to it, they should be able to exercise their judgment——

Chairwoman HORN. OK.

Mr. BOWERSOX [continuing]. On the date.

Chairwoman HORN. So to sum it up, not until a new Administrator is named? OK.

Mr. BOWERSOX. That's the short answer, yes.

Chairwoman HORN. OK. Why haven't Orion and SLS contracts for vehicles beyond EM–2 been definitized? And when will they be definitized? What strategy are you using to incentivize contractor performance in these contracts?

Mr. BOWERSOX. Well, it's critical to get those contracts in place for Artemis 3, so we're working that very hard. It's one of our top priorities right now. And we expect to have the Orion contract in place within a month or so, very, very soon, more like a year probably for the SLS contract.

Chairwoman HORN. OK. Did you carry out—and this is, I think, a very important question in some of the realignments. Did you carry out an assessment of the costs, risk, and safety of using a more capable SLS Block 1B versus multiple commercial launches to stage a lunar landing to Mr. Cooke's point? Just a yes or no, was there an analysis conducted?

Mr. BOWERSOX. Yes, we've considered that.

Chairwoman HORN. OK. So in the analysis, the Committee would very much like to see that analysis, and if you can provide that to us, please. So when do you plan——

Mr. BOWERSOX. And I should correct—I mean we have considered it. I have not seen an analysis——

Chairwoman HORN. OK.

Mr. BOWERSOX [continuing]. But I'll see what we've got and tell you that.

Chairwoman HORN. OK. So it has been considered, but there may not be a full written analysis of that——

Mr. BOWERSOX. Yes, what we're most worried about is having enough cores to do that in time for a 2024 landing.

Chairwoman HORN. OK.

Mr. BOWERSOX. You know, with our production issues.

Chairwoman HORN. OK. And when do you plan to use the EUS on an SLS launch, and what is NASA doing to implement that plan?

Mr. BOWERSOX. Right now, we're looking at where we can use EUS. At this point, the earliest we would probably be able to use it is around Artemis 4, but we need to work that internally with our budget estimates. Right now, our current plan would be to go ahead without the EUS. That's what's in our official President's budget submission. However, Congress has been very helpful in providing funding for EUS. And so the earliest we would be likely to use it is Artemis 4.

Chairwoman HORN. OK. I think any information that you have we'd like to see an analysis of the decision metrics there, so if you can provide that to us as soon as possible, that would be great.

Mr. BOWERSOX. All right. And just to restate what our Administrator has said, we want EUS. It will be very helpful in our architecture, and we understand that.

Chairwoman HORN. OK. Ms. Chaplain, you raised some very important points, and in my opening statement noted that we have seen some serious challenges in the SLS, Orion, and EGS during the development. And while we need to right the ship and fix current problems, we're also working on a NASA reauthorization. And so looking forward, I have a couple of questions for you. Could you summarize—I'll just give you a few and let you answer it once because I think these go together. Could you summarize some of the lessons learned that can be applied to future programs, and what specifically can this Committee and Congress do to ensure that these actions are taken? Finally, is it a matter of oversight, or are there areas that need to be addressed in the authorization to set up the programs for success as we address the issues that we've experienced moving forward?

Ms. CHAPLAIN. I think much of what has been done is not really—that should be done is not something you can legislate. They're really just basic good practices that NASA should be following. And I think at various times they've been called on to do that.

When we look at the problems from like a higher-level perspective, we see a couple things that I'll go through, and I think it'll help you see where we need to target things going forward. One thing is they've made it very difficult to understand where money is going in those programs and what's being spent in the future. There has been some language congressionally out there to make sure that happens, to make sure we get the right baselines for costly elements of the programs, as well as future flights and as well as cost estimates for missions and to just have better tracking of costs within the program over time.

Also, the programs have not always used the management tools that they have available to them that talk about things like award fees, really exercising them to not reward good performance, incentivize performance when it is good. That's what I meant.

And then other kinds of tools like even standing review boards and independent assessments, they tend to give NASA a range of estimates, high, low, where things could go. NASA tends to take the low estimates. And that's—sort of goes to the overall theme of optimistic estimating and hoping everything's going to go right.

And then again as I mentioned earlier, just following best practices when you develop cost estimates, when you lay the groundwork for programs, there's a lot that could be done there. There were efforts to adopt some very good practices like joint confidence level for these programs, but I think even in doing that there's things within those methodologies that could be improved.

Chairwoman HORN. Thank you very much. Mr. Cooke, I'll have questions for you later, but I want to make sure everybody gets a chance, so, Mr. Babin, you're recognized.

Mr. BABIN. Yes, ma'am. Thank you very much.

Mr. Cooke, your testimony references numerous studies that all conclude that the optimal lunar exploration mission architecture features two SLS launches since it decreases the number of launches necessary, thereby increasing mission success. And it allows for a wider lander with a lower center of gravity that is more stable when landing.

NASA, however, is pursuing a plan that requires multiple launches on less capable rockets, more in-space docking, and a narrower lander. Based on decades of trade studies, does this make any sense to you? And is NASA relying on commercial launch vehicles because they don't believe that they will have two SLSs available by 2024?

Mr. COOKE. My short answer is, no, it doesn't make sense to me. When you divide up your lander, there's an ascent vehicle and a descent vehicle. It even has to be fueled at the Gateway by launching on smaller vehicles. It constrains the payload diameter as well, so it limits the size of the lander. These things, for one, it can cause the lander to get taller, which then makes it less stable on the slope on a lunar surface.

Mr. BABIN. Right.

Mr. COOKE. But it also limits what you can fly on it. Right now, the requirements look to be based entirely on an ascent vehicle for the crew. However, if you do the work to lay out the long-term architecture and what you're actually going to achieve on the Moon, it'll have to transport other things like a habitat potentially, rovers. And without those requirements when ending up with a small lander, you may not be able to build the capability that you need to be sustainable.

Mr. BABIN. OK. Thank you. And also, Mr. Cooke, the Orion Crew Vehicle and the European Service Module are less capable than the Apollo Command Module and Service Module because the European Service Module (ESM) is based on the Automated Transfer Vehicle that provided cargo to the ISS. This led NASA to propose a transfer vehicle in their concept of operations for a Moon landing. The NASA Aerospace Safety Advisory Panel recently stated that the ESM propulsion system continues to raise issues that affect both safety and schedule. Why doesn't NASA just ensure that the European Service Module meets the requirement of enabling a crewed lunar landing rather than starting an entirely new development?

Mr. COOKE. The Service Module is obviously key to the architecture in terms of getting the crew where they need to go. The distribution of where propulsion goes and the fuel needs to be worked out. I believe NASA needs to really own the lunar landing and get the architecture together to do it most effectively.

Mr. BABIN. OK. And then, Mr. Bowersox, what does NASA need to do regarding spacesuits to enable a crewed landing in 2024? Does NASA plan to change the plans that they laid out in the spacesuit plan delivered to Congress a few years ago?

Mr. BOWERSOX. Well, our current plan is to have the suit developed at the Johnson Space Center. There's been a lot of work that's been going on there for years and years since I was an astronaut. And we're going to build on that work to have JSC manage a program and develop a lunar suit for us.

Mr. BABIN. OK. Great. And then one other question for you. Recently, we heard of potential issues with the delivery of the Orion spacecraft to Plum Brook for testing. Apparently, the margins for the Super Guppy, the airplane that is planned to transport the spacecraft, could be insufficient to handle a potential emergency landing based on the weight of Orion and the container that it's shipped in. What is the status of this review, and will Orion make it to Plum Brook on schedule? And will NASA have to use the Pegasus barge and go through the St. Lawrence Seaway to be potentially iced in over the wintertime? And if so, would this impact the use of the Pegasus barge for transporting the core stage to Stennis this winter? I know that's several questions wrapped up, but if you could answer those. I'm running out of time.

Mr. BOWERSOX. So, yes, you sort of hit all the issues on everything we're working——

Mr. BABIN. Absolutely.

Mr. BOWERSOX [continuing]. But the bottom line is the latest news is we're very hopeful that the Guppy is going to work out. Our most likely backup options would be other aircraft options, for example, the Beluga aircraft that they have over in Europe right now would require some extra time, but we still think we'd be ready for the launch of Artemis 1 that we're sort of forecasting.

Mr. BABIN. OK. So we don't have to deal with ice, and iced in the St. Lawrence Seaway, huh?

Mr. BOWERSOX. No, sir. We were all worried about that, too, but we think we're——

Mr. BABIN. OK.

Mr. BOWERSOX [continuing]. Going to be OK.

Mr. BABIN. All right. Thank you. And I yield back.

Chairwoman HORN. Thank you, Mr. Babin. The Chair recognizes Mr. Crist for 5 minutes.

Mr. CRIST. Thank you, Madam Chair. Thank you to our panelists for being with us today.

Mr. Bowersox, I'm pleased that NASA has moved forward with the award of the Mobile Launcher 2 contract this summer. Can you provide an update on the status of the second Mobile Launcher and discuss how this additional capability at the Kennedy Space Center will support the goal of returning humans to the surface of the Moon by 2024?

Mr. BOWERSOX. Yes, sir. We expect to start construction on the second Mobile Launcher late this year, and that program is going pretty well. There's lots of lessons learned from the construction of the first Mobile Launcher that we're building on, and that's going to enable us to use an SLS Block 1B or Block 2 later with an Exploration Upper Stage.

Mr. CRIST. Mr. Cooke, do you have anything to add to that?

Mr. COOKE. I fully support the—moving ahead on the ML–2. It's important for where—what we need to get to the larger SLS vehicle and will—it will be important for our lunar exploration.

Mr. CRIST. Thank you, sir. Mr. Bowersox, can you discuss the NASA plan for Orion and the Space Launch System, also known as SLS, after returning humans to the surface of the Moon for 2024?

Mr. BOWERSOX. The first three missions we expect to launch on roughly 2-year centers, and then after that, we'd like to go to one launch every year for the SLS with an Orion, and that would be our cadence for all the lunar missions.

Mr. CRIST. Specifically, will SLS be used to transport segments of the lunar Gateway or lunar orbit?

Mr. BOWERSOX. If we get EUS in future budgets, we would be able to take some elements of Gateway or potentially logistics elements out to lunar orbit with the Orion vehicle.

Mr. CRIST. Can you discuss how SLS and Orion will be modified and utilized for travel to Mars?

Mr. BOWERSOX. Well, one of the things I like about our current plan is that we wouldn't need to do much modification for SLS or Orion to go to Mars. We'd like to have the cargo version of SLS ready for Mars so we can transport the large diameter heat shields we think will be required to enter Mars, but that's one of the good things about our architecture is it's not just the Moon, it's also Mars, it's both.

Mr. CRIST. Does NASA have a plan or a timeframe for SLS and Orion to get humans to Mars? Or, if not, is such a plan in development?

Mr. BOWERSOX. That plan is in development, and we're—and very detailed discussions inside the agency.

Mr. CRIST. Again, Mr. Cooke, would you like to also comment on the future of SLS and Orion?

Mr. COOKE. The future of SLS and Orion is based on both lunar and Mars exploration. When we did the design back in—actually a final design—for getting to the current concept of SLS was in 2011. It was—they were designed for Moon and Mars missions. That was the criteria.

Mr. CRIST. Mr. Bowersox, I've always been fascinated by the potential for life to exist elsewhere in our universe. I was intrigued by the news last week that water vapor was found in the atmosphere of an Earthlike exoplanet. Can you discuss how SLS and Orion might help contribute to future exploration of the universe and a search for life, whether it be launching larger, more powerful telescopes or through future deep space exploration even beyond Mars?

Mr. BOWERSOX. Well, to me that's one of the most exciting things about having the capability like the Space Launch System is we don't know exactly what we'll do with it yet. But as we develop it, as we generate the ability to make cores more predictably, I think we'll have lots of opportunities to do the types of things you're talking about.

Mr. CRIST. Great. Mr. Cooke, in your testimony, you write that, quote, "Exploration capabilities should be made available for commercial and other interests to further the utilization of space." I assume that also includes academic interests, perhaps to support the search for life elsewhere. Could you elaborate on your point?

Mr. COOKE. The value in having a vehicle like SLS fully developed with the lift capability and the—and not just lift capability but what's important is the volume of payloads and the diameter that is allowed on the top of the core stage. This allows for larger-aperture telescopes. For instance, the James Webb Space Telescope which I'm looking forward to see fly, has to be deployed. You can get to the larger, simpler spacecraft with that capability. And the lift capability can allow you to actually get places quicker with upper stages that will accelerate and get to outer planets and—and so it provides a lot of opportunity that's fully yet to be worked out.

Mr. CRIST. Great. Thank you. Madam Chair, I yield back. Thank you.

Chairwoman HORN. Thank you, Mr. Crist. The Chair recognizes Mr. Lucas.

Mr. LUCAS. Thank you, Madam Chair.

Mr. Bowersox, let's just cut to the chase. If NASA does not receive the additional $1.6 billion for Fiscal Year 2020 or some anomaly in the continuing resolution to fund things, will it be able to achieve a crewed lunar landing in 2024? How important is this money?

Mr. BOWERSOX. The amendment and the ability to spend that money if we have a continuing resolution is critical to getting to the lunar surface in 2024. We need it to start our human landing system program.

Mr. LUCAS. So basically it blows a big hole in the program if we are not properly funding you?

Mr. BOWERSOX. Well, we wouldn't give——

Mr. LUCAS. It makes it more complicated, how about that?

Mr. BOWERSOX. It makes it much, much harder, yes, sir.

Mr. LUCAS. Mr. Cooke, let's go back to, again, the 20,000-foot view, as we would say in western Oklahoma. How does exploration of the Moon enable us to explore Mars?

Mr. COOKE. The exploration of the Moon does help in a lot of ways. In terms of getting to critical operations on another planetary body that we haven't done in 50 years, there are hostile environments that have to be encountered at both places that you have to learn to design for. Many of the systems that will be designed will involve two Mars systems if not be used as-is. But in going to Mars the trips are so much longer that reliability is——

Mr. LUCAS. Days versus months and years?

Mr. COOKE. Yes, 500- to 1,000-day missions. Everything has to be very reliable because you're sending a crew, and you want to return them safely. So getting to reliable systems can be proved out in an operational program like the lunar program. You tend to spend the effort on the technology you need in an ongoing program. A lot of times, technologies programs can get defunded or money taken to do other things. But if you're on a direct path and have clear goals, then you know that you have to get it done. So it's a forcing function, too.

Mr. LUCAS. Mr. Bowersox, let's touch on this again. What is the earliest that Artemis 1 could be launched? And what's the limiting factor?

Mr. BOWERSOX. The earliest that we could launch Artemis 1 at this point is roughly at the end of next year. We've got to get it out of the factory, which we think will happen at the end of this year. We have at best 5 to 6 months for testing and another 5 to 6 months of processing at the Cape before we could launch. And then if you start throwing in weather delays, any potential technical problems, anything that we have to fix after we fire the engines, that adds on extra time and it's just hard to say exactly what will happen until we get there.

Mr. LUCAS. But at this stage you have a certain amount of time built in the concept of going at the end of 2020, correct?

Mr. BOWERSOX. Yes, sir. We've got some likely delays that are based on previous programs and previous performance, but there's less judgement involved in interpreting those numbers.

Mr. LUCAS. Mr. Cooke, the Aerospace Safety Advisory Panel often cites the launch rate of SLS as a concern. What's the maximum number of times SLS could launch in a year? And what would those limiting factors be when we're up and going?

Mr. COOKE. My understanding is that the current rate is going to be two a year. I don't know the limit on what they are—Ken can probably speak to that. But I'm concerned about the rate because when we start going to Mars, you're going to have to go more than twice a year to get assembled the vehicles that you have. It will take on the order of six or more SLS launches at full capability to send a crew to Mars. So they can't wait for however many years that is, so it's important to get the rate up.

Mr. LUCAS. Speaking of that, Mr. Bowersox, Henry Ford demonstrated a century ago that if you move enough product down the assembly line, costs will come down, efficiencies will increase. So after the initial development of SLS and Orion, NASA will transition to operation contracts for the procurement. What cost reductions does NASA expect to see in that next generation of contracts?

Mr. BOWERSOX. Well, we're working those contracts now, so I don't really want to get into specifics, but we expect to see some reduction and some improvement in the rate with which we can produce the cores at the Michoud Assembly Facility.

Mr. LUCAS. And we'll need those savings to achieve that greater production rate.

With that, I yield back, Madam Chair.

Chairwoman HORN. Thank you, Mr. Lucas. The Chair recognizes Ms. Hill.

Ms. HILL. Thank you so much, Madam Chair. I have a couple questions.

Mr. Bowersox, what is the current status of the prime contracts for the SLS core stages and Orion crew capsules beyond Artemis 2?

Mr. BOWERSOX. The contracts are in negotiation. We're closer on getting the actual contracts signed for Orion for Artemis 3 and beyond. We expect that fairly soon and expect on the order of a year before we'll see the core stage contract award.

Now, in the meantime, in order to purchase long lead items so we don't have delays, we work on definitized contracts actions, letter contracts to buy long lead parts. And there's some risk in doing that——

Ms. HILL. Yes.

Mr. BOWERSOX [continuing]. But that's what we're doing.

Ms. HILL. Do you think NASA will be transitioning those procurements to fixed-price contracts from cost-plus contracts?

Mr. BOWERSOX. Well, what we've been trying to do is for each of the contracts to transition from cost-plus to fixed-price. Sometimes it happens during the contract.

Ms. HILL. OK. And, Ms. Chaplain and Mr. Cooke, can you each comment on NASA's decisions on when to use cost-plus versus fixed-price contracts for SLS and Orion procurement?

Ms. CHAPLAIN. I would say generally for space programs, when you transition to the phase where you are producing higher numbers of whatever spacecraft there is, that's your opportunity to really get into the fixed-price contracting. When you're in the earlier stages, there's a lot of uncertainties about what you're doing. The government does need to take on more risk at those stages unless they have plenty of contractors willing to sign up for prices that might not be well understood.

Mr. COOKE. I totally agree with Ms. Chaplain.

Ms. HILL. Great.

Mr. COOKE. One aspect of this, though, is in getting a fixed price say, on the SLS is it's not just the core stage. It's boosters, it's engines. And NASA is currently the integrator. If you want to get to a fixed price on a launch vehicle, it would seem to me that it would be better to have that combined under a prime contract that then has control—where the owner of the prime contract has control of all the processes and can—and actually bring some of these efficiencies to bear.

Ms. HILL. That makes sense. And then, Mr. Bowersox, the GAO reported in its assessment in June 2019 of the human exploration systems programs that because both SLS and Orion cost and schedule have exceeded the contract values, NASA plans to renegotiate the Boeing contract for the first two SLS core stages and the Exploration Upper Stage and modify the cost and period-of-performance aspects of the contract with Lockheed Martin for the first Orion crew capsules. So can you talk about the current status of those updates? I know that you said that things are underway.

Mr. BOWERSOX. It's in process, and we'll talk about all that when we have a named——

Ms. HILL. OK.

Mr. BOWERSOX [continuing]. Associate Administrator.

Ms. HILL. Great. And can you just say that is NASA modifying the award fee and incentive structure in the renegotiated contracts?

Mr. BOWERSOX. One of the things we're looking at for everything we're doing is how we're handling incentives. We want to incentivize the performance that we desire from our contractors.

And, I mean, I think we can all agree that we're not seeing the performance we want, and so we should be looking at those.

Ms. HILL. Great. And in that same assessment, it showed that the integration and testing phase of development often reveals unforeseen challenges leading to cost growth and schedule delays. Anything you want to add to why that is?

Mr. BOWERSOX. Well, the first time you try anything, it's harder. And we are seeing a lot of improvements the second time we do things, the second Orion build, the second core stage build. There's great progress there, and so we have a lot of—we have a great chance to do better on three, four, five in each of the production lines.

Ms. HILL. So given those—you know, how it tends to be unforeseen things that come up, how much cost and schedule margin or reserve would you recommend for SLS and Orion heading into this integration and testing phase?

Mr. BOWERSOX. Well, at this point we'll take as much extra reserve as we can get, right? But we don't think we need to ask for a lot more than what we've put in the budget at this point. It's—and in the next phase we should be more predictable. It's the new programs where we really want to be thinking about reserves——

Ms. HILL. Excellent.

Mr. BOWERSOX [continuing]. So that we have flexibility, yes, ma'am.

Ms. HILL. And, Ms. Chaplain, what are the top risks to cost and schedule that you see for SLS and Orion integration and testing?

Ms. CHAPLAIN. So I still see a lot of risk ahead. It will be a different type of risk because you're putting things together, shaking them up and down, testing them, firing them. And all those activities tend to reveal problems that need to be fixed that could cause a bit of rework. You might have to go back into vehicles, reopen them, and adjust components. If you look at the James Webb program, we saw substantial delays, substantial problems come up in integration and testing. They might be focused on a very small screw, a valve, things like that, but they can cause a lot of delay.

Ms. HILL. Great. Thank you all so much. I yield back.

Chairwoman HORN. Thank you very much. The Chair recognizes Mr. Brooks.

Mr. BROOKS. Thank you. I've got an article in front of me entitled, "Getting Back to the Moon Requires Speed and Simplicity," and it purports to be by Doug Cooke, opinion contributor, and it goes on to say Doug Cooke is a former NASA Associate Administrator. I just want to make sure that's the same Doug Cooke who is before us today.

Mr. COOKE. Yes, sir.

Mr. BROOKS. All right. Let me quote from it in three different places. Quote, "Apparently under pressure from commercial launch providers who need additional launches to fill their manifest, NASA is being directed to break the lunar lander into multiple pieces so that these can fit on less powerful commercial launchers, increasing risk and constraining the architecture," end quote.

Second quote, "NASA's current approach requires eight new developments"—interjection by me, versus three with Apollo, eight to three—resuming the quote, "eight launches versus one with Apollo and approximately 17 mission-critical operations versus seven with Apollo to achieve the Artemis goals by 2024," end quote.

And then finally, quote, "If you assume each event has a 98 percent probability of success, the likelihood of mission success is 80 percent for this Apollo-like approach in comparison. The likelihood of mission success for NASA's current approach is 51 percent, not taking into account the launch vehicle maturity risk. NASA can significantly increase speed, simplicity, cost, and probability of mission success by deferring Gateway, leveraging SLS, and reducing critical mission operations," end quote.

Now, if I were an astronaut, I'd be concerned about these kinds of comments from a former NASA Associate Administrator. And they appear to suggest that profit motive, i.e., the desire of some individuals for personal gain, may be driving NASA decision-making at much greater risk to our astronauts.

So I'd like to have, Mr. Cooke, if you would expound on that leaving enough time for Bowersox to reply.

Mr. COOKE. I think that the pressure to get to commercial capabilities and drive that objective is causing us to do things that are higher risk. And going to this many developments from scratch, by the way, starting now, trying to get to 2024, with that many critical mission events, the probabilities are that. And if you assume .98—and .98 is arbitrary, and some of the numbers would be higher, some would be lower—but it's illustrative of the complexity that's been bought into versus what could be done with a more simple approach.

Mr. BROOKS. Mr. Bowersox, could you please give us your view on these comments?

Mr. BOWERSOX. Yes, sir. First, nobody's driving us. I mean, we actually came to these conclusions on our own. And a big driver is to have flexibility. We want to have multiple options. We don't want to rely just on one system. We'd like to have other systems. And what we're trying to build on is some of the success we've experienced in having flexibility with our commercial cargo vehicles for station. Having multiple providers, multiple options there has been really useful. When one has a problem, we can go to the other provider. And so we want to take advantage of some of that learning and move it into this other program to help us get to the Moon and on to Mars.

Mr. BROOKS. Well, if I could interject for a moment, do you concur with Mr. Cooke's belief that the Apollo method of going to the Moon was simpler and safer versus the current Artemis approach of going to the Moon?

Mr. BOWERSOX. What I would say about the Apollo approach it was—is that it was simpler. I wouldn't say that it was necessarily safer. That will—you know, we'll know that after we're done. But I think that our current approach has a lot of potential to be actually safer than Apollo. Even because of the flexibility and complexity, we can actually increase some of the safety aspects.

Mr. BROOKS. Mr. Cooke, in the time that I have remaining, do you have any additional comments you would like to give on this subject?

Mr. COOKE. Just that it gets back to probabilities in the end and critical events, critical launches. And it's—the more that you have, the higher the risk. We did succeed with Space Station, which was about 40 Shuttle launches to build. Had we lost a payload during that time, we didn't have backups. We didn't have the margin and budget to have backup hardware. So if we had lost one of those payloads, we would have been scrambling. So it's better to keep it simple. It's hard enough as it is.

If you watch the documentaries from Apollo 11 and saw the team in the control room who I grew up under at Johnson Space Center, you saw the—their anticipation of every burn, every docking, every possible critical operation. You saw their anxiety leading up to that point and the relief when it was done. So the fewer that you have like that, the better you are, I think, and less risk.

Mr. BROOKS. Thank you, Madam Chair.

Chairwoman HORN. Thank you very much. The Chair recognizes Mr. Perlmutter.

Mr. PERLMUTTER. Thanks, Madam Chair. And I appreciate everybody's testimony today. Thank you very much for being here.

Ms. Chaplain knows where I'm going with my line of questioning, and it really is pretty simple. My goal is that we get to Mars by 2033. And there are a whole variety of things that can happen, different ways to do it, and I'm not a technician, I'm not a scientist, I'm not an engineer, and I rely particularly on you two gentlemen and all the people that are working on this to figure out the best way to do it. And if going to the Moon first is a great stepping stone to ultimately get to Mars, that's what I want to do. Ms. Chaplain knows my job is to help find the money to get this done, which is not that easy but obviously is a key component to all of this.

So my question to all three of you is, have we lost sight of—in this process of Artemis and getting to the Moon, have we lost sight of what I hope is the ultimate goal of getting our astronauts on Mars 2033? Mr. Bowersox.

Mr. BOWERSOX. Sir, first, thanks for showing us the bumper sticker.

Mr. PERLMUTTER. Yes. I'll put it right there.

Mr. BOWERSOX. I love to see your excitement, and I share it. I want you to know that. And I want to assure you that the Artemis program is part of our Moon-to-Mars effort. And we have worked really hard to keep the horizon goal of Mars in sight in all of our integrated planning.

Mr. PERLMUTTER. Ms. Chaplain, since you get to kind of watch this from the money side.

Ms. CHAPLAIN. Right. It would have been a challenge even without this focus on Moon right now to get to Mars if that's all we focused on. It's going to be a big challenge to get to the Moon again by 2024. That leaves you 9 years left to get to Mars. I think it's still very challenging even if you had, as you desire, you know, unconstrained amounts of funding to get there. That would help——

Mr. PERLMUTTER. That's a nice way to put it, thank you.

Ms. CHAPLAIN. Yes, but it's still going to be a challenge. It's worth trying, but it's a challenge.

Mr. PERLMUTTER. No, and I think you and I have had this conversation. I mean, this is a big challenge. This is a huge task. This is difficult, you know, to say the least. But there are ways to do it, and I think we have the capability. And, as you and I have talked about, this is going to be—and my hope is it's NASA-driven, it's public-private, and it's international in scope so that there are others assisting in partnership with us getting to Mars. But my job is to work with you and our appropriators to make sure the funding is available as the technology develops and the plans develop.

Mr. Cooke, please.

Mr. COOKE. Yes. I am fully on board with getting to Mars. And I think that, for the reasons I stated earlier, the Moon is an important step, and it helps force the technologies and the operational capabilities to do that. In fact, I talk about deferring the Gateway for the first lunar lander, but the Gateway, in my view, could be the prototype for a Mars transit vehicle. And if you did it that way, tested out those technologies like life-support systems, the power and propulsion element that's a part of it now as high-efficiency propulsion for in space, those kind of things, if they're tested out right and thought out and not hurried, they can end up being prototypes for the actual in-flight mission to Mars. So I think it fits together, but it takes putting together a long-term plan so that you see where each of these aspects fits in the big scheme of things.

Mr. PERLMUTTER. OK. Thank you all. I yield back to the Chair.

Chairwoman HORN. Thank you very much, Mr. Perlmutter. I realize I should have said I recognize Mr. Perlmutter and his bumper sticker. We knew that was coming.

The Chair recognizes Mr. Posey.

Mr. POSEY. Thank you, Madam Chair, for holding this hearing, and I thank the witnesses for coming and sharing with us today.

Previous IG and GAO reports have indicated there have been some issues with the Exploration Ground Systems software. I wondered if you could update me on the status of that. Mr. Bowersox first.

Mr. BOWERSOX. The latest I'm hearing is that we're getting through those issues, and we should be on track to meet whatever earliest Artemis 1 date we can get. When we can get the stage there, the ground system is going to be ready is what I'm hearing.

Mr. POSEY. Anyone else want to comment?

Ms. CHAPLAIN. I'd say just generally the delays being experienced on the hardware side have given the software side more time to work out their issues. The hardest part is always on the ground system side that is at Kennedy because they have to respond to any changing requirements from Orion and SLS. So to the extent that there's still some changes going on, there will always be some changes going on on the software side.

Mr. POSEY. OK. Thank you. Following up on a question Mr. Crist previously asked about the second Mobile Launch Platform. What why did it take so long to issue a contract for that?

Mr. BOWERSOX. I'll get back to you on details on that one, sir. I'm not exactly sure. That was a little before my time. But I know we're underway right now and planning to start construction at the end of the year.

Mr. POSEY. Has the delay of construction prevented SLS from complying with the NASA authorization requirements to reach a 130-ton launch capacity?

Mr. BOWERSOX. I wouldn't say that delay is going to interfere with reaching that particular goal. There's probably other complexities that might delay us from getting to that goal. But it is still our eventual goal at around Artemis 9 or 10.

Mr. POSEY. OK. How confident are you that we'll have boots on the Moon by 2024?

Mr. BOWERSOX. How confident? I wouldn't bet my oldest child's upcoming birthday present or anything like that. But what I'll tell you is, having that aggressive goal is really good for us. It is helping us focus. It's helping us keep track of what's important inside our agency. And so we're working toward it as hard as we can. And I think it's healthy for our whole organization.

Mr. POSEY. Do you think we'll make it?

Mr. BOWERSOX. Well, we're going to do our best to make it, but, like I said, what's important is that we launch when we're ready, that we have a successful mission when it launches. And I'm not going to sit here and tell you that just arbitrarily we're going to make it. We have to have a lot of things come together to make it happen. We have to get our funding, we have to balance our resources with our requirements, and then we've got to execute it really well. And so there's a lot of risk to making the date, but we want to try to do it.

Mr. POSEY. OK. Mr. Cooke, what do you think? Where are you placing your bets?

Mr. COOKE. I would agree with Ken on what he said. I think it's important to have the urgency in the program to get things done. These programs require constant problem-solving, and there is a way to go to get to the Moon based on the things that have to be done, but the sense of urgency is important in programs so it's not business as usual. You're working off problems. But I support getting to the Moon as soon as possible. I don't have insight into the exact program schedules and details, so I couldn't honestly say. But I support getting there as quickly as possible.

Mr. POSEY. OK. Ms. Chaplain?

Ms. CHAPLAIN. Yes, I also agree that having aspirational goals is good. It's still a lot of risk in getting there. You're having to manage a lot of programs that need a lot of new development within a short period of time. But to manage things like that, there are some things you can do like having a very detailed architecture to help you manage all that overlap that you're going to be experiencing; having good configuration management so when changes are introduced, people could really weigh the cost of those changes and the effects they have and understand the implications that they have; having good visibility in the progress and being very open and transparent is very necessary so that you guys understand what's ahead and maybe what more resources are needed; and then having very good communication lines within the agency and with contractors is important.

Mr. POSEY. OK. What do you think the odds are commercial will beat you? Mr. Bowersox?

Mr. BOWERSOX. The odds that commercial will beat us to the Moon?

Mr. POSEY. Yes.

Mr. BOWERSOX. I'd still bet on us.

Mr. POSEY. All right.

Mr. BOWERSOX. But they might be part of our program.

Mr. POSEY. Mr. Cooke?

Mr. COOKE. I agree with that answer. I believe that the program that was laid out for going to the Moon is the best chance of getting there. And to do it as simply as possible will get us there the quickest. There is a role for commercial in this. I don't know that anybody can beat the government program because of its capabilities.

Mr. POSEY. OK. I see my time is expired. I yield back. Thank you.

Chairwoman HORN. Thank you very much. The Chair recognizes Mr. Olson, although she has to wonder if he was so scared of OU beating Texas that drove him to retirement in the intervening time.

Mr. OLSON. I thank the Chair. And I have to say congratulations, my dear friend. Your Sooners, 49; our Houston Cougars, 31. Great victory, great, great victory, but I'd like to point out that never, ever would've happened without a native Texan, your quarterback, from Brian Babin's district Jalen Hurts. And as my dear friend knows, there's this big game called the Red River Rivalry. Hook 'em horns. Beat Oklahoma.

Chairwoman HORN. You notice which school he chose?

Mr. OLSON. He made some mistakes with Alabama first.

Thank you, Mr. Bowersox, for talking about the focus at NASA Johnson Space Center. I moved there in the summer of 1972. Apollo 16 had come home. Apollo 17, its last mission to fly that December. I saw the excitement, the focus, and then we hit the 1970s, just nothing of importance, three Skylab missions, Apollo-Soyuz, just nothing, kind of this lack of focus, delays, flying a Space Shuttle, building a Space Station, all the focus again constantly just is wiped out, no focus. Then we're going back to the Moon. More focus. And so, as you guys said, I think that's why mission in force.

My concern is we built the Saturn V rocket for one mission, to take three people in a craft that can land on the Moon to the Moon and bring them back. The SLS was made out of a concept of going back to deep space without a mission per se at the time to take it there.

So my question is, have there been challenges building that rocket to the ever-changing Mars, Moon, whatever missions? Is it on track, a challenge we can help out with? Because I know it's tough. Apollo was very clear: Moon, three men come back. This one, Mars, Moon, deep space. Any concerns there?

Mr. BOWERSOX. Well, you're pointing out a really good problem, and that is if you change your approach too often, then the whole process can become muddled and it can make it difficult to get where you're going. I think that's something that you guys can help us with is consistency of direction and help us maintain a consistent approach. And that will give us a much better likelihood of reaching our horizon goal of Mars with Moon to develop that capability.

Mr. OLSON. Thank you. And then I've got to focus on the Johnson Space Center because that's by my home. And this question is for both you again, Mr. Bowersox, and Mr. Cooke. What role should

JSC have in astronaut training and mission operations for things like Gateway and the lunar lander? How do these lunar landers being taken care of, the same stringency as the Apollo missions? Because that expertise, while fading, is still by the Johnson Space Center. And now it looks like that may be going to Marshall. So my question is, are you satisfied? Can we help get this right? Because I think we have the expertise there with the landers, the Gateway.

Mr. BOWERSOX. Well, first of all, you know, one of the things we try to do at the agency is balance out our activity across all of our centers so we can take advantage of the best at each center. And we thought that for the human landing system Marshall's specialty in propulsion would really help them in the management of that program since a big part of that whole landing system is the propulsion system.

But I want to assure you that Johnson Space Center folks, especially the folks in flight operations, mission control, the astronauts will be heavily involved in developing all the crew interfaces that will be required to operate the vehicle. They're going to be critical working with Marshall to get that vehicle done so that it's successful.

Mr. OLSON. Mr. Cooke, any comment to that, sir?

Mr. COOKE. I totally agree with what Ken is saying. I think the Center for Human Spaceflight Mission Operations is in Houston. It needs to keep focus on what's coming and prepare for it. I think the capabilities are still there.

Mr. OLSON. Final question to you, Mr. Bowersox. After we develop the SLS and Orion, NASA will transition to the contracts for operations to the private sector. Does this reduce costs, and how do you expect to see those reductions in contracts coming after that? Is it a viable program is my question.

Mr. BOWERSOX. Well, part of the idea of increasing the amount of programs we do commercially is to get more fixed-price contracts and get more competitive incentives to help reduce the cost. I mean, that's one of the things we're trying to do so that we can do more with the resources that we have. But we still have to prove that that's really going to occur, right? There's still some risk that it won't. But we're seeing positive signs with our commercial cargo providers.

Mr. OLSON. And that was my question, I just want to get the Chairwoman involved, a current endeavor we all support, as I'm sure you do, Mr. Bowersox. Go Navy, beat Army. I yield back.

Mr. BOWERSOX. Thank you, sir.

Chairwoman HORN. As you can tell, we don't have any fun on this Committee either.

The Chair recognizes Mr. Waltz.

Mr. WALTZ. Thank you, Madam Chairwoman. And as a 23-year veteran, I have to say go Army, beat Navy. It's bipartisan.

Mr. Bowersox and Mr. Cooke and Ms. Chaplain, I just have to take a step back. And I know you just had questions along these lines from Mr. Olson. I get asked by Floridians all the time where space is really in our DNA and folks follow this very closely down in my district in northeast Florida. I was asked by a constituent the other day why NASA can't go over to the Air and Space Museum and dust that lunar lander off, upgrade that thing, and get it back on the SLS that you're rebuilding and let's go?

And we laugh, and that obviously skips over a lot of technical details. But it does get to the heart of the issue of why a lot of Americans and a lot of Floridians struggle to understand why it feels like we are inventing the wheel. We did this a long time ago with a lot less technology, and so as someone who's new to this Committee, I cringe when I hear it's going to take us another 6 years to develop a spacesuit or that we're talking decades to get back to where we were decades ago.

So can you just kind of elevate a little bit because I think all of us in this Committee and all of us who care about space exploration are going to continue to make the case and have to make the case of not why this is worth the funding but why it is taking so much time and so much effort and so many delays and so much money frankly to get back to where we were.

Mr. BOWERSOX. Well, first, that's a great question, and it's something that I think about every day. I think we've done it before, why is it so hard to do it again? And one of the things I see is we do things differently now, and often we want to take less risk. And that is one of the biggest challenges we've got. So I keep trying to get people to go back and look at what we actually did on the lunar module for Apollo, what did we do with the suits back then to remind——

Mr. WALTZ. From a process-wise——

Mr. BOWERSOX. From a process——

Mr. WALTZ [continuing]. And a culture.

Mr. BOWERSOX [continuing]. Point of view and a culture point of view to help remind us of the type of risks that we accepted in the past and to see if it's appropriate to inform our risk decisions in the future.

Mr. WALTZ. Yes, go ahead, Mr. Cooke, and——

Mr. COOKE. It's really a complicated question and answer I think. There are a lot of facets to it. You're absolutely right it was done and a lot of those technologies were proven. Some of them have been abandoned for a long time. We found when we made the decision on the SLS propulsion that a great answer for propulsion on a launch vehicle from Earth is a big kerosene engine, which we had on Saturn V. But we haven't done a big kerosene engine since then. The Shuttle was LOX (liquid oxygen) hydrogen, and that drove us to go that direction. So we can walk away from capabilities that take some time to get back.

Now, on the other hand, it shouldn't really take all that long to develop these things. I'm fully on board with getting them done as quickly as possible. And actually if you have some urgency, it keeps alternate ideas and new requirements from creeping in, which is part of the reason it does take longer because——

Mr. WALTZ. You're talking about the——

Mr. COOKE [continuing]. Because——

Mr. WALTZ [continuing]. Great idea factor——

Mr. COOKE. Yes, the great ideas.

Mr. WALTZ [continuing]. We call it in the Army.

Mr. COOKE. Because we have more capability and technology, we want to fit them in somehow. I mean, that's typical for an engineer to make want to make things better. So we get trapped in that to some degree I think.

Mr. WALTZ. So just in the interest of time, what I really want to get to—and the Chairwoman mentioned it—what do you think NASA needs from the Congress and the Administration particularly as this Committee works toward a reauthorization to meet our goals of getting on the Moon? I know we have the broad agency announcement out for a commercial human landing center. We've discussed in the terms of—the Committee has discussed in the context of Artemis that, you know, NASA plans to award contracts to at least one provider that can safely deliver humans to the Moon annually beginning in 2024. What do we need? What do we need to get done this year, short-, medium-term to hit that goal?

Mr. BOWERSOX. Well, first, we appreciate your support, and we know we've got it. Consistent guidance and the resources. And for this year what we need is that budget amendment so we can get the landing systems awarded, get those contracts out because that's our long pole right now for getting to the lunar surface.

Mr. WALTZ. What would you say is the outside window of the date to get that contract actually awarded?

Mr. BOWERSOX. Well, roughly the end of the year. And then, you know, it slips after we go past the end of the year is what I'd say.

Mr. WALTZ. OK. Thank you, Madam Chairwoman. I yield.

Chairwoman HORN. Thank you, Mr. Waltz. The Chair recognizes Mr. Weber.

Mr. WEBER. Thank you, Madam Chair, for allowing me to sit in here and audit your class. I've learned more about football today than I thought I'd ever know.

Mr. Cooke, I know you were at NASA for a few years during the Obama Administration when Lori Garver served as Deputy Administrator. I would remind the Committee that Ms. Garver is one of the architects of the policies that actually terminated the Space Shuttle and the follow-on Constellation program, which wound up resulting in our dependence on the Russians for access to the International Space Station since 2011, almost a decade now.

Mr. Cooke, she has penned an op-ed, Ms. Garver has, on July 18, 2019, about NASA's purview in her opinion. Have you read that article by chance?

Mr. COOKE. I don't recall it right off——

Mr. WEBER. OK. Well, it's 2 days before the Apollo 11 anniversary where she advocates actually for the termination of NASA's Human Exploration programs and return to the Moon, which she calls, quote, "meaningless new goals," end quote, and said NASA should instead be turned into an agency to study global warming. And you've not read that article, *Washington Post*, July 18, 2019.

Mr. COOKE. I did read it, yes.

Mr. WEBER. OK.

Mr. COOKE. I didn't remember——

Mr. WEBER. It's becoming a bit more familiar, sounding a bit more familiar now.

Based on your experience, you've been around a long time, 45 years as I read your bio in the space program. Based on that experience, does it surprise you that she would be advocating against

NASA's human spaceflight programs and to focus NASA basically on global warming research at the expense of the space program?

Mr. COOKE. I don't want to get into differences, you know, of that nature necessarily, but it doesn't really surprise me. I obviously——

Mr. WEBER. That's fair enough.

Mr. COOKE [continuing]. I feel differently obviously.

Mr. WEBER. Sure. And I appreciate that. Do you perceive any danger of that actually happening?

Mr. COOKE. I honestly don't know. I think that you all in Congress have kept us on a course in human exploration for a long time and have been the conscience——

Mr. WEBER. Right.

Mr. COOKE [continuing]. Of various ideas that have floated in and out. I know that while I was Associate Administrator and had the Constellation program——

Mr. WEBER. Right.

Mr. COOKE [continuing]. At that time——

Mr. WEBER. I read that.

Mr. COOKE [continuing]. And it was Congress that led us to where we are today with the Space Launch System and Orion.

Mr. WEBER. Absolutely. And let me follow up with that with Mr. Bowersox in exchange. Congressman Waltz said he cringes when he thinks that it takes 6 years to build the spacesuit, so, Mr. Bowersox, as NASA is preparing for a crewed lunar landing and a pressing need to upgrade the Extravehicular Mobility Unit, spacesuits used for ISS spacewalks, they need to be upgraded as well, how will NASA prioritize each of those efforts if they have a constrained budget environment?

Mr. BOWERSOX. Well, the good thing is they sort of go together. The way we've got the programs set up now, the components we develop that can be used on the lunar surface can also be used at the ISS. And we would test them at the ISS first, at the Station first.

Mr. WEBER. But should it takes 6 years really?

Mr. BOWERSOX. You know, there's a certain amount of time that things take in the aerospace world, and 4 to 6 years seems to be about what you get no matter how much money you throw at it. I would like it to be faster, and we're looking for ways to be faster.

Mr. WEBER. OK. Are there roadblocks along the way that you can identify, or is that just it, it takes 4 to 6 years and you're just resigned to it taking 4 to 6 years? Is there anything we can do to shorten that timeframe?

Mr. BOWERSOX. I think you guys are giving us plenty of support, and we appreciate it. I think our folks at JSC have been working on it plenty of years now, and so with the right resources, I think we might be able to accelerate it some.

Mr. WEBER. OK. Do you know where we are currently in that timeline?

Mr. BOWERSOX. Yes, sir. Right now, we'll have the suits developed and tested in time for an Artemis lunar landing and a test on ISS somewhere between now and then.

Mr. WEBER. So that's a long way of saying we're somewhere between now and then?

Mr. BOWERSOX. Yes, so roughly 5-1/2 years from now.

Mr. WEBER. OK. So Mr. Posey posed the question about the 130-ton capacity SLS. With all the equipment that we would have to move up for the Moon to be deposited up there and work, how many trips will that take, any idea?

Mr. BOWERSOX. With our current plan it would take one launch of the SLS with the Orion, the crew would go up, but prior to that launch we'd position the stages for the lander, which could be somewhere between two and three, and then depending on what we need for additional supplies, we might have an additional mission, so somewhere between three and four small launches.

Mr. WEBER. Will that be the prototype to also go to Mars? And what's the gravity difference between Mars and the Moon? Do you know offhand?

Mr. BOWERSOX. Mars is roughly 4/10 of the gravity on Earth. The Moon is roughly 1/6——

Mr. WEBER. Right.

Mr. BOWERSOX [continuing]. The gravity of Earth. For Mars we would probably see similar type of launch rates but very likely with the bigger vehicles, with——

Mr. WEBER. Right.

Mr. BOWERSOX [continuing]. Whatever large cargo vehicles are available.

Mr. WEBER. And I know I'm over time, but one last question. You spent 200-and-something days on ISS?

Mr. BOWERSOX. Well, only about 150-some——

Mr. WEBER. Not that you were counting.

Mr. BOWERSOX. Yes.

Mr. WEBER. So we're now——

Mr. BOWERSOX. I would've liked to stay longer.

Mr. WEBER. So now we're talking about a trip to Mars that takes how many days?

Mr. BOWERSOX. Well, in some of our estimates it could be 3 years.

Mr. WEBER. OK. All right. Thank you, Madam Chair, for your indulgence, and I yield back.

Chairwoman HORN. Thank you very much. I'm glad that you're here auditing the class. Always appreciated.

Mr. WEBER. Thank you.

Chairwoman HORN. So I have a few more questions. We're going to go through one more round because I think that it's pretty clear based on the questions that we've seen on both sides that there's some outstanding issues, and I want to touch on a couple more things before we wrap this up.

So starting off, I think there's some clarity—I share many of the concerns with my colleagues on both sides of the aisle about heavy lift and, Mr. Cooke, I read the same article and have many of the questions. So I want to very clearly ask you, Mr. Bowersox, is NASA requiring the use of commercial vehicles to launch the lunar landing system? You said you wanted options, but I want to be clear. I'm understanding these as requirements, so can you clarify that for me?

Mr. BOWERSOX. That's what's in our plan is that we're going to use commercial rockets to launch the landing systems.

Chairwoman HORN. OK. So NASA is requiring, which is not the same as having options. It's a requirement——

Mr. BOWERSOX. It's——

Chairwoman HORN [continuing]. In this plan?

Mr. BOWERSOX. It's a requirement in the SLS, but, I mean, we should be careful about what our definition of commercial systems is. You know, there's lots of different rockets out there. We don't even know what is going to be developed in the future, so it's hard to say exactly which rocket will launch our landing systems. And we're open to options. We just want to make sure that there's some competitive pressure, and we'd like our providers to get their launch vehicle commercially.

Chairwoman HORN. I'm going to let you say something. I'm going to respond very quickly that I think, just to be clear, there is no commercial launch vehicle that is capable of launching—or has demonstrated launch capability for the 15 megatons right now, which is the minimum of one?

Mr. BOWERSOX. We don't have a vehicle that has actually demonstrated that capability, but we've got multiples in development.

Chairwoman HORN. OK. And, Mr. Cooke, I'd love to hear your thoughts on this.

Mr. COOKE. In talking about competition for vehicles, currently, the SLS cannot compete probably legally because it's a government system. It is integrated by the government. The requirements are driven in the government, and there are different contracts. There's the core stages, which has been talked about a lot. There is also the Northrop Grumman boosters. There are also the rocket engines, the main engines. They're all different contracts. As a government-owned and operated program, I don't think legally it can compete if it's to be a competition.

Chairwoman HORN. Thank you. That was an important clarification.

And I have many more followups on that. When we're talking about the heavy lift needs and capabilities, and, Mr. Cooke, I'd love to hear little bit more on that point because if we're talking about a human, I agree, a schedule and goals that are lofty are important. And we've also seen some of the challenges and the lack of certainty when we've gone back and forth, and I think that's what we're working on is to build certainty into this as much as we can because there's a lot of unknowns and unknowns that we're going to discover as we do the hard things moving forward.

And it seems clear to me that there is a need for a heavy lift launch vehicle, and there is a vast distance between what SLS has been planned for and the upper—and the heavy lift portion of that and some of these others. So I think my question to you, Mr. Cooke, is, what difference that would make practically in breaking it up? I know we've talked about risk and in having a more integrated system in our pathway to Mars using the Moon as an interim step.

Mr. COOKE. I think it's very important that you be able to launch as much integrated hardware as you can without having to assemble it, which brings on complications. It potentially creates heavier interfaces between them. When you join two pieces of space hardware, they are birthed or docked and they have connections, they have fluid transfers, they have—if you can integrate that on the ground and have it tested, it's much simpler than trying to put it together in space, which will require an incredible amount of analysis and planning operationally and risk in it actually happening correctly. So being able to launch an integrated lander all at once is a simpler, more straightforward approach. And it provides more—having the larger volume and mass capability allows it to be the size it needs to be for transporting the various elements that will go to the Moon, not just the ascent vehicle but also habitats.

Another thing is going to a small lander because of the constraints currently placed and having it launch on a commercial launch vehicle may drive the fuel that's used on the lander to be storable like what we call hypergolic fuels that are different than fuels that you might use that you get from the Moon. There's hydrogen and oxygen on the Moon in the form of ice, we think, in the craters at the poles, and if you're using storable fuels on your lander, that's one less place you can bring that to bear and I think diminishes the possibility of commercial development at the Moon.

Chairwoman HORN. Thank you. That's very helpful. And adding on, I've got a couple more followups, and then I think we have just one more individual that wants to ask a second round of questions. Following up on that, I would just like to reiterate that the analysis about cost and benefit, I believe that there is value in developing commercial capabilities. There is absolutely a space for it. We've seen it in so many other places. And I am concerned that the decisions are not being driven by what is most efficient or effective and what is most cost-efficient. And to reiterate that seeing those analyses from NASA and having the assurance that NASA is going to respond to the GAO request and to follow these procedures is critical.

This is an investment of our taxpayer dollars, and we are all, I think, on this Committee, on board in understanding the need for us to help set course that can be followed and prevent some of the stops and starts and to advocating for sufficient funding. And it's very difficult for us to do that if we don't know what the cost analysis is, if we don't have transparency, if we don't see that the analysis has been done, if there is a decision that has been made that is not based on the most clear path, we know part of this is risky. And strapping people to rockets and sending them out of Earth's orbit is always going to be risky, and it's also an endeavor worth undertaking.

And as the Committee with responsibility for oversight and authorization, it's also incumbent upon us to ensure that our taxpayer dollars are being spent wisely and that our investments as a Nation are being guided. And so what we need to see is an analysis of this, why these decisions were being made, what is driving them because options are important, and if there is not an analysis to back it up, why are these decisions being made? So we can set this up for success.

Ms. Chaplain's report really shows many of these things, and it's not to undermine NASA. In fact, I think it's to support our human exploration program that we need full visibility on these decisions, so that we can better advocate and educate the public and our colleagues about what is happening and what it's going to take to get this done.

And so to that end one more question I think is important, Mr. Bowersox, because you have mentioned this a couple of times, that decisions won't be made until a new Associate Administrator is selected. So my question is has NASA identified finalists? How close are we? Because working on tight timelines is impacted by the lack of an individual who can make those critical decisions. So where is NASA in that process?

Mr. BOWERSOX. Well, first, I want to reassure you we're working tactically every day to make the decisions that need to be made and moving forward on anything that could compromise our 2024 date.

And NASA—I mean, it's—I'm not handling the selection. It's being handled by our 9th floor A suite. They're working really hard work talking to candidates, and I think they've got a goal to actually be through with that process by the end of the year. And it's hard work. And we want to give them all the time they need because we want them to find the right candidate, right? We could be in a lot worse situation if we got the wrong candidate into the job.

Chairwoman HORN. Thank you very much. Ms. Hill, you're recognized.

Ms. HILL. Thank you so much. Mr. Bowersox, I just wanted to follow up on a letter that the OIG (Office of Inspector General) sent indicating that NASA will use the first three SLS flights for the Artemis missions and as a result could not have an SLS available for the Europa Clipper until at least 2025. Is that accurate?

Mr. BOWERSOX. Right now, we think that's accurate.

Ms. HILL. OK. What's the status of development of the cargo variant of the SLS payload fairing that would be used by Europa Clipper?

Mr. BOWERSOX. Well, right now, by law there's certain work that we have to provide to launch Clipper, and so we have a cargo fairing for Clipper in work. And as part of the negotiations for this follow-on core contract that we talked about earlier—3 through 12—we're hoping that we can get to the flight rate where we would actually be able to provide an SLS to launch Clipper. But again, that requires performance that we haven't seen.

Ms. HILL. NASA stated that it's aiming for an SLS launch cadence of approximately one per year. What if anything would prevent launching more than one SLS in a year? And how much would it cost to produce an additional SLS flight unit?

Mr. BOWERSOX. Well, most of the costs that go into a vehicle like that are sort of fixed costs. The marginal costs are much less. I probably shouldn't quote a number, but it's a lot less than what we, you know, would spend for each individual year. And because it's under negotiation in the contract, I don't want to give that number. But we could do it for less to do that extra core, and it's a challenge that our team is looking at and would like to be able to provide that core for Clipper.

Ms. HILL. So you think it's possible to do an additional one per year?

Mr. BOWERSOX. I'm not ruling it out right now, but we have to see performance that we haven't seen yet, so I don't want to promise it to you.

Ms. HILL. OK. And then switching gears for a second, so we talked about how some of the delays have to do with being willing to take less risk than we did previously. And I know at least some of that is risk to human life. We've talked about that with the spacesuits and I want to talk about ISS and what we've learned on the International Space Station over the last 19 years that enables us to more safely send astronauts to operate for longer periods of time in deep space. What more can we gain from additional year-long missions or other human research testing on ISS to prepare for these missions? And, generally speaking, is that an asset that we will face, you know, problems from losing with lack of access to it?

Mr. BOWERSOX. Well, ISS is an integral part of our Moon-to-Mars strategy. I mean, everything fits together from the surface of the Earth up to the surface of the Moon and then out to Mars. What we need ISS for, is to gather the data on how humans live in microgravity. Right now, the longest we've seen is roughly a year with a U.S. crewmember, and we're talking about potentially 3-year missions to Mars. So we need that data. We need to see just what the risks are.

Ms. HILL. And would either of you like to respond as well?

Mr. COOKE. The International Space Station was designed to do those things. It was designed to get us the data we need for long-term existence in space and prove technologies and test hardware that we'll need for reliability.

Ms. HILL. Ms. Chaplain?

Ms. CHAPLAIN. I don't have additional comments.

Ms. HILL. OK. I have 1 minute and 30 seconds. Anything else you want to add before we wrap up just generally?

Mr. BOWERSOX. Sure. The other stuff we want to do on the ISS is test the life-support systems that we use to go to Mars. Those have to be super-efficient and super-reliable. The best place to test them is some place close to Earth, and we're doing a lot of that at the International Space Station.

Ms. HILL. Great. Anything else you want to add on a subject not related to ISS?

Ms. CHAPLAIN. I'd like to comment on what Chairwoman Horn was saying. In terms of going forward, you hear a lot of different alternatives, preferences that people have and reasons for having them. It really makes it important to develop a robust analysis of alternatives before you embark on these programs so that you do understand costs, schedule, performance, and the reasons why certain choices were made.

We do have a study going on about that like what are they looking at in terms of their analyses for the ways forward, so hopefully by early next year, you'll see the results of that work.

Ms. HILL. Well, thank you so much. I really appreciate your time. I yield back.

Chairwoman HORN. Thank you, Ms. Hill.

And thank you, Ms. Chaplain, for mentioning that. We look forward to seeing the results of that study. Bottom line, we're all trying to do the best, and I think the more information we have that we can for the agency, for our Nation, for many different reasons, and the more information we have and the more clear it is, the better decisions that we can make. So I thank you for that and look forward to seeing that study.

Before we bring the hearing to a close, I want to say thank you to all of our witnesses. I hope that it's clear that we are determined and dedicated to asking the hard questions, to make sure that we set NASA up for success and that we are being responsible to our taxpayers and to making sure that we're making the best decisions possible. And we really appreciate your expertise.

I also want to say that the record will remain open for 2 weeks following this, and we are likely to follow up with some written questions for the record for each of you.

Again, thank you to the witnesses. Thank you to everyone who's here and to the other Committee Members for your participation.

And we're now adjourned.

[Whereupon, at 11:58 a.m., the Subcommittee was adjourned.]

Appendix

Answers to Post-Hearing Questions

Answers to Post-Hearing Questions

Responses by Mr. Kenneth Bowersox

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE AND AERONAUTICS

Developing Core Capabilities for Deep Space Exploration:
An Update on NASA's SLS, Orion, and Exploration Ground Systems

Questions for the Record to:

Mr. Kenneth Bowersox

Submitted by Chairwoman Horn

1. How is NASA currently determining cost growth for the SLS program, and does that determination include any reduction in the mission scope as compared to the original mission scope and Exploration Mission-I (EM-I) cost baseline?

- **What is the current level of cost growth NASA is managing for SLS EM-I development?**

A: As of the President's Budget Request for FY 2021, NASA reported the Space Launch System (SLS) development cost had increased by $1.73 billion over the base year development cost estimate. These costs are based on definitions set in the original Management Agreement and Agency Baseline Commitment (ABC) intended to account only for Exploration Mission-1 (EM-1, now Artemis I) SLS activities. As HEOMD has updated its non-baseline estimates, it has reclassified certain EM-1 costs from EM-1 to non-EM-1. These adjustments were intended to more accurately account for EM-1 costs. The Agency followed its NPR 7120.5 guideline, which is newly applied to multi-mission/multi-flight capability programs with fixed base and variable costs.

2. I understand that NASA is reporting development cost growth for the Orion program against an internal launch date of September 2022 rather than against the agency baseline commitment date of April 2023. Is measuring cost growth against an internal target launch date rather than the baseline commitment date, which includes schedule reserves, standard practice for NASA flight projects?

A: NASA formally measures cost and schedule against the Agency Baseline Commitment estimates. For Orion, that is April 2023. However, for management, NASA works toward internal planning dates (and related information, such as cost) to enable managers to better focus on making progress towards achieving milestones at the earliest practicable point. The planned rebaseline of Artemis I will provide the opportunity to also evaluate cost and schedule for Artemis II.

3. During the question and answer session of the hearing, you stated, in response to a question from Congresswoman Hill, that "one of the things we're looking at for everything we're doing is how we're handling incentives." How, if at all, is NASA changing its approach to incentivizing contractor performance in the Orion Production and Operations Contract (OPOC) and in the contract for SLS beyond the second flight, Exploration Mission-2?

A: The first six spacecraft under the Orion Production and Operations Contract (OPOC) will be acquired by cost-plus-incentive-fee ordering. NASA will negotiate firm-fixed-price orders for future missions to take advantage of the anticipated spacecraft production cost decreases. Furthermore, the cost incentives on the cost-plus-incentive-fee orders are designed to motivate favorable cost performance during early OPOC production and drive substantially lower prices for any subsequent firm-fixed-price orders issued under this contract.

On the Space Launch System (SLS) contract, NASA has provided initial funding and authorization to Boeing to begin work toward the production of the third core stage and to order targeted long-lead materials and cost-efficient bulk purchases to support future builds of core stages. This action allows Boeing to manufacture the third core stage in time for the 2024 mission, Artemis III, while NASA and Boeing work on negotiations to finalize the details of the full contract within the next year. The new contract is expected to realize substantial savings compared to the production costs of core stages built during the design, development, test and evaluation phase by applying lessons learned during first-time builds and gaining efficiencies through bulk purchases. Reducing these costs will be essential to successfully pursuing the Artemis program.

4. During the question and answer session of the hearing, I asked to see any analysis with respect to cost, risk, and/or safety that NASA has done in considering using SLS Block IB versus multiple commercial launches to stage the cargo and infrastructure for a lunar landing. Please provide that analysis.

A: Generally operational risk can be reduced when fewer in-space operations are required such as multiple in-space Rendezvous Proximity Operations and Dockings (RPOD). However, this potential risk must be weighed against other risk factors, such as launch vehicle reliability and flight experience, short- and long-term development and operational costs, and safety of people and systems.

5. What risk reduction demonstrations or tests on the ground and in space is NASA requiring as part of the development of the Human Landing System?

- **When would those demonstrations be required to take place?**
- **What is the overall risk mitigation strategy for the Human Landing System?**

A: Please refer to Next Space Technologies for Exploration Partnerships (NextSTEP) Appendix H (Human Landing System), and specifically Attachment G, HLS Statement of Work (Oct. 16, 2019 version), as posted at Federal Business Opportunities at the link below:

https://beta.sam.gov/api/prod/opps/v3/opportunities/resources/files/9486b282378ccd8054aa6bbb341a1137/download?api_key=O4kzViWGVYNumPqhAzUhYGiZZZwW3RKUEYJOI6ii&token

6. What is the current status of the Exploration Upper Stage development, including recent and upcoming major milestones and challenges?

A: While the SLS Block 1B configuration with the Exploration Upper Stage (EUS) remains an important future capability, NASA's near-term focus is the successful completion of Artemis I, II, and III and supporting a reliable annual flight cadence. Production challenges for completion of the Artemis I core stage are serious and require that NASA and its contractors concentrate in the near term on the successful completion of the vehicle and its safe and reliable launch.

However, the EUS is an important part of Artemis infrastructure long-term. Per appropriations direction, SLS will continue design and development of the Exploration Upper Stage (EUS) and work toward the EUS Critical Design Review (CDR) in FY 2021.

7. Which Orion systems, capabilities, or technologies necessary for the first crewed flight test (Exploration Mission-2) of SLS/Orion will not be flown on the uncrewed flight test (Exploration Mission-I)?

- **How will those systems that will be needed for the crewed test (but not flown on the uncrewed test) be tested before flight?**

A: The Orion spacecraft used for Artemis I will include the active thermal control system but no environment control and life support systems, while the Orion used for Artemis II will add the active environmental control and life support systems, and add other crew accommodations, including displays and control systems. It is not effective to add these capabilities without a demand for – or consumption of – such capabilities (e.g., on Artemis I, there will be no one to breathe the oxygen generated and then exhale carbon dioxide and humidity into the scrubbers, and no one to interact with the displays). Testing of life support components to be flown on Artemis II (including the Orion spacesuits) will include ground-based testing, as well as demonstrations aboard the International Space Station (ISS). NASA is confident that this development plan is sufficient to ensure that Orion's life support and other crew systems will work properly on Artemis II.

8. What are some of the breakthroughs and innovations to come out of the SLS, Orion, and EGS development effort, and how, if at all, are they being used in the broader industry and aerospace community?

A: Orion, SLS, and Exploration Ground Systems (EGS) teams are using the latest in systems and manufacturing technology with the intent of developing a safe system capable of extending human presence into the solar system. For example, the Orion team is using time-triggered Ethernet and is taking advantage of the standards for this technology that are used in the automotive industry. Both Orion and SLS are utilizing friction-stir welding (including on large structures, such as the SLS core stage), with the largest friction-stir weld machine in the world. The EGS team has stripped out the old copper cables from Pad 39B and replaced them with the latest in fiber optics. Orion and SLS plans take advantage of advances in additive manufacturing, or "3D printing." For example, Orion is using this technology to reduce testing costs by printing test versions of flight hardware for use at the Integrated Test Lab in Denver, while SLS is assessing the use of 3D printed parts in future RD-25 engine production. These are just some examples of how NASA's Exploration Systems are utilizing and advancing the latest in technology.

The development efforts for NASA's exploration programs are delivering additional value beyond the physical hardware from which the Nation and the aerospace industry both benefit. As a publicly funded agency, NASA shares data and technical expertise with companies. NASA's facilities greatly contribute to the national capability of aerospace research, design, and testing for use by commercial partners. Major modifications to support Orion testing at Plum Brook Station resulted in facilities available for companies to use, including SpaceX, Blue Origin, and others. Exploration Systems Development leverages more than 3,800 suppliers and over 60,000 workers. These highly capable workers represent a national asset. Aerospace companies can hire these skilled workers for their teams or contract with other companies that employ engineers with specialized skillsets.

9. What, if anything, is needed to help prepare the NASA workforce for future deep space human exploration development programs?

A: It is important for the Nation to maintain constancy of purpose in its deep space human exploration programs since this will help to provide a measure of stability to the U.S. industrial base and enables NASA and industry to attract the best and the brightest to the aerospace field.

Additionally, NASA needs to modernize employment policies and practices in order to maintain a vibrant and productive workforce in the near- and long-term. Already, NASA has had success in reducing hiring times from 90 days to 30 days. Additionally, working with the Office of Personnel Management, NASA was recently approved for an extensive Direct Hire Authority for NASA, covering approximately 3,600 positions across 26 different occupations, authorized for the next five years. In addition, we are aggressively working to fill critical positions with our limited authority for excepted service positions designated in the Space Act (U.S. Code 51, Chapter 201, Section 20113(b)(1)).

As NASA begins to implement the President's direction to achieve a moon landing by 2024, while implementing the direction of Space Policy-1 to "[l]ead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities", it will require continuing to adapt the existing NASA workforce to be more familiar with working on human spaceflight development. The Orion, SLS, and EGS programs have provided excellent development opportunities for NASA workforce to learn firsthand about operating in a development environment. This experience and understanding gained will be leveraged to continue the development associated with the future Artemis mission elements.

10. What is the scope and duration of the Green Run test?

- **What is the anticipated time following the test that NASA plans to spend on analysis of the test data?**

A: During the Green Run testing, engineers will install the SLS core stage, which will send Orion to the Moon in the B-2 Test Stand at NASA's Stennis Space Center near Bay St. Louis, Mississippi for a series of tests over several months. The term "green" refers to the new hardware that will work together to power the stage, and "run" refers to operating all the components together simultaneously for the first time. Many aspects will be carried out for the first time, such as such as cryogenic fill/draining operations, pressurizing the stage, and the test series culminates with firing up all four RS-25 engines to demonstrate that the engines, tanks, fuel lines, valves, pressurization system, and software can all perform together just as they will on launch day.

The test program for the core stage at Stennis will begin with moving the Core Stage via the Pegasus barge, off-loading, and installing the stage into the test stand. Then, engineers will turn the components on one by one through a series of initial tests and functional checks designed to identify any issues. Those tests and checks will culminate in an eight-minute-long test fire, mimicking the full duration of the core stage first flight with ignition, ascent and engine shutdown. This includes first time software utilization, as well as newly refurbished SSC B2 Test Stand facilities. The results of this test also will provide important data that will confirm how the system reacts as the fuel depletes from the propellant tanks.

The SLS program is performing the stage testing with flight hardware. Once the validation of the stage is complete, the entire stage will be checked out, refurbished as needed, and then shipped to NASA's Kennedy Space Center in Florida for the Artemis I launch.

11. NASA's independent Aerospace Safety Advisory Panel (ASAP) has raised concerns about Orion's European Service Module's serial propellant system design. How is NASA responding to the ASAP's concerns, and does NASA's approach include transitioning to a parallel system after the first three flights of Orion?

A: The Orion Program is reviewing whether future European Services Modules (ESMs) – those used beyond Artemis III – will involve any additional system design changes. The Agency will keep the Aerospace Safety Advisory Panel apprised.

12. The Government Accountability Office (GAO) and the NASA Inspector General have both expressed concerns about NASA's ability to estimate per-launch costs of the SLS. At what point in the development process does NASA expect to understand the marginal per-launch cost of SLS, and how would NASA calculate it?

A: After development is complete in the late 2020s, NASA currently estimates that the annual cost of the program flying SLS once per calendar year is approximately $2 billion per year in real year dollars. This cost provides a Block 1 launch vehicle with the ability to carry a crew in a deep space capable vehicle, with all the capacity, safety, and redundancy required for a deep space mission. SLS is the only planned vehicle capable of launching Orion to the Moon.

The calculation of cost for a marginal flight is highly assumption driven, with many different factors that can cause significant variances in the result of the calculation. We understand and share the GAO and NASA IG's concerns. Cost estimates for marginal launch costs are now higher than we originally targeted. As NASA finalizes negotiations with contractors and procures future flights sets this year, we will have a better understanding of marginal and total launch costs of the SLS.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE AND AERONAUTICS

Developing Core Capabilities for Deep Space Exploration:
An Update on NASA's SLS, Orion, and Exploration Ground Systems

Material for the Record

Chairwoman Horn
Pg. 34, line 737; Pg. 35, line 764; Pg. 82, line 1911; Pg. 83, line 1937

Please provide any analysis with respect to cost, risk, and/or safety that NASA has done in considering using SLS Block IB versus multiple commercial launches to stage the cargo and infrastructure for a lunar landing.

A: Generally operational risk can be reduced when fewer in-space operations are required such as multiple in-space Rendezvous Proximity Operations and Dockings (RPOD). However, this potential risk must be weighed against other risk factors, such as launch vehicle reliability and flight experience, short- and long-term development and operational costs, and safety of people and systems.

Rep. Posey
Pg. 61, line 1399

Why did it take so long to issue a contract for Mobile Launch Platform-2?

A: The period between availability of appropriated funding and contract issuance was shorter than normal for this type of contract. NASA conducted a two-step design-build procurement for Mobile Launcher 2 (ML2) in accordance with Federal Acquisition Regulation 36.3 - Two-Phase Design-Build Selection Procedures. The Phase 1 solicitation was a Request for Qualifications in order to determine the most highly qualified offerors to compete in Phase 2. Phase 2 was a Request for Proposals issued to the offerors down-selected during Phase 1. This is the fastest that the Kennedy Space Center has ever awarded a cost reimbursable contract of this magnitude/complexity using the Two-Phase Acquisition process – essentially 12 months, not including the Government shutdown, which occurred in the middle of the process.

Responses by Ms. Cristina Chaplain

1. In the 2016 "Assessment of Major Projects" report, the Government Accountability Office (GAO) noted the dissolution of NASA's Independent Program Assessment Office and cautioned that dissolving that office could involve potential acquisition risk and have impact on project oversight. Do you continue to have concerns about NASA's decisions to eliminate the Independent Program Assessment Office? Why or why not?
    a. How important is NASA's internal, independent capability to estimate, assess, and monitor cost and schedule to the effectiveness of the agency's program management?

We continue to believe that it is important for NASA to have a capability to independently estimate, assess, and monitor cost and schedules to provide decision makers with additional information regarding the performance of NASA's major projects. As part of our annual assessment of NASA's major projects, we are currently assessing what challenges, if any, NASA is facing with regards to the dissolution of the Independent Program Assessment Office. We look forward to further discussion on this topic once we have completed our assessment.

2. In your written testimony, you noted several technical challenges that GAO identified as major factors in NASA's inability to meet the June 2020 launch date for Exploration Mission-I (EM- I), such as issues with SLS core stage development, the Orion avionics, and ground system software. Of the major technical challenges that GAO sees as the cause of the latest delays, which ones are resolved, and which remain unresolved?

Our prior work has shown that the integration and test phase—the phase that the Space Launch System (SLS), Orion, and Exploration Ground Systems (EGS) programs are currently in—often reveals unforeseen challenges that can lead to late-cycle cost growth and schedule delays. NASA's recent announcement that the manufacturing of the first SLS core stage at Michoud Assembly Facility is complete is a significant accomplishment for the program. However, the program still needs to complete green run testing, which is the first time NASA will fuel the completed core stage with liquid hydrogen and liquid oxygen and fire the integrated four main engines for about 500 seconds. In addition, this test carries risk because it is the first time several things are being done beyond just this initial fueling. For the Orion program, delays with the European Service Module and components issues for the avionics systems for the crew module contributed to the program's inability to support a June 2020 launch date, but these have since been resolved. The capsule is now undergoing testing at a NASA vacuum testing facility in Plum Brook, Ohio. The EGS program has overcome challenging development hurdles—including completing and moving the Mobile Launcher into the Vehicle Assembly Building—that led to previous schedule delays. Looking ahead, software testing and verification is still ongoing and the EGS program is responsible for the final integration of the three programs, which is likely to be an area that reveals unforeseen challenges.

3. NASA maintains that a delay in the launch date for Exploration Mission-I (EM-1) to as late as mid-2021 will not affect the schedule for Exploration Mission-2 (EM-2). Do you agree with that assessment? Why or why not?

While NASA maintains that a delay in EM-1 (Artemis I) will not impact EM-2 (Artemis II), we believe this is an area that requires continued attention because of the scope of work that needs to be accomplished between the missions. For example, NASA plans to reuse some avionics components from the Orion spacecraft used in Artemis I on Artemis II. NASA officials told us this reuse will take approximately 20 months to complete. As a result, there is a minimum amount of time that must occur between the two missions unless NASA pursues an alternative strategy for the Artemis III avionics.

Responses by Mr. Doug Cooke

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE AND AERONAUTICS

Developing Core Capabilities for Deep Space Exploration: An Update on NASA's SLS, Orion, .and Exploration Ground Systems

Responses to Questions for the Record from Chairwoman Horn

Submitted by Douglas R. Cooke

1. Question: As I understand NASA's current plans, the second crewed launch of the integrated SLS- Orion system would carry an astronaut crew to the Moon to conduct the lunar landing with the Human Landing System (HLS), and the only in-space demonstration NASA will require the HLS to have conducted before this crewed lunar landing is an uncrewed docking and undocking operation. Could you share your perspectives on the risk posture for this approach?

   Response:

   The risk posture for HLS will be dependent on the extent of the entire test program leading to the human lunar landing. This will include the extent/adequacy of ground testing, simulation and analysis. NASA is currently competing the HLS through a Broad Agency Announcement (BAA), so the final design is not defined, and therefore the exact test plan cannot be complete at this point. The competition is for lander services. Therefore the proposals will include not only the lander, but how it is delivered and operated. This will include the launch vehicle(s), potential assembly of the HLS and potential fueling of the HLS. If the HLS is assembled and fueled in space at the Gateway, testing will be more complex and the probability of success will be less than if the lander and ascent vehicle were integrated and tested to the degree possible on the ground and then launched already assembled. This is an example of the point I made in my testimony about the probability of success being dependent on the number of launches and critical operation. It is possible to reduce the risk through thorough ground testing of all systems in relevant environments. Propulsion tests, environmental chamber tests, simulations, and other component tests will be needed to ensure safety and success. The detailed test plans will undoubtedly be negotiated between the provider and NASA. It is possible that acceptable risks can be achieved without more extensive flight testing, but it depends on these factors.

2. Question: In response to Representative Perlmutter's questions, you noted that the Gateway could be the prototype for a Mars transit vehicle. Could you please elaborate on that idea?

   Response:

   My view is that every flight element developed for human exploration should be leading directly to what is needed for long term exploration of the Moon and Mars. That is to keep the expense to a minimum, because these budgets are precious. The Mars Architecture will need to have a transit vehicle for the crew to travel from the vicinity of the Earth to Mars orbit and back. The habitat for the crew will need to be large enough for their health and well-being. There will also have to be a large habitat landed on the Mars surface for their lengthy stays (determined by orbital transit opportunities between the two planets). These two habitats should be as close to the same design as possible. There will also be a Mars lander/ascent vehicle. Advanced propulsion will be required for these missions that is more efficient than what can be achieved with current chemical propulsion to keep the amount of fuel to a more reasonable amount (a factor of 2 difference in overall mission mass launched from Earth). All of these have to be launched from Earth. Mass efficiency is important to keep the number of SLS launches to a minimum. At best, it will still require six or more launches. There are over 30 years of study that have borne this approach out.

Based on our best knowledge of hardware heritage and emerging technological improvements, NASA should design for the Gateway habitat what we think the actual hardware for a Mars transit crew habitat would be. Numerous studies have shown that it should be a large volume for the 6+ month transits to and from Mars. One of the reasons for the SLS design is for cargo volume in addition to the mass it can lift. The diameter and volume of a Mars transit habitat should take advantage of the large SLS cargo payload capability. The habitat should be outfitted with the best designs for ECLSS, power, thermal, avionics, radiation protection, etc. At the outset of the Gateway operation NASA should begin to test the systems for reliability (extremely important for lengthy missions to and from Mars), getting time and experience on the systems. Make the systems modular, so upgrades can be implemented, where reliability improvements are demonstrated to be needed or significant efficiencies can be gained with improving technology. Design it as though we are checking out the actual Mars transit habitat. Maybe it will be.

Crew radiation exposure on the long transits to and from Mars is one of the biggest crew health risks for these missions. The radiation protection designed into the Gateway/Mars habitat would accurately provide the health data needed, because it would be the correct configuration. This is very important, since the crew exposure to Galactic Cosmic Radiation (GCR) is very different with different module, radiation protection, and system hardware designs. GCR is much less of an issue in Earth orbit due to the protection provided by Earth's magnetic field.

The current Gateway Power and Propulsion Element (PPE) is a reasonable precursor in developing more efficient propulsion. After testing it, the capability would have to be scaled up for Mars missions. This capability would be used for sending the lander and surface habitat. For crew missions to Mars a faster transit would be required. Nuclear thermal propulsion should be considered, so their mission is as short as possible. This would be separate development from the Gateway and not needed until the first Mars mission.

The habitat might have to be replaced for various reasons before the first Mars transit, but the replacement would be more of a recurring unit (less expensive than a completely new design) that has necessary upgrades. In this scenario the Gateway flight experience and testing would be the most representative and valuable for Mars missions as opposed to a capability based on smaller modules constrained by lesser launch capability. Orion missions to this Gateway/Mars habitat would provide more meaningful missions and experience for the crews.

The process of checking out the "Mars transit vehicle" would also generate more public and stake holder excitement and interest.

3. In response to Representative Perlmutter's questions, you also discussed the need for a long- term plan. What would you expect to see in a well-thought-out, long-term plan

Response:

I have testified on this subject to this subcommittee in the past on May 21, 2013, titled "Next Steps in Human Exploration to Mars and Beyond". Some comments have been overtaken by events. I will repeat the most relevant parts of that here that I still believe are the right approach:

Developing a Rational Long-Term Exploration Strategy

Based on years of planning for the future of human space flight, leads me to advocate the following approach.

To begin with, the strategy's ultimate long-term goals need to be widely accepted within the broad space flight community. These ultimate goals should include answering fundamental questions:
1.) What are the large geo-political goals that we want to achieve with human spaceflight?
2.) What should be our country's long-term vision for future human space exploration? and,
3.) How do we envision collaborating with international partners, considering their aspirations and strategies to achieve this vision?

I believe the first 2 questions, at a minimum, should initially be answered without the constraints of specific budgets and schedules. Instead, we should acknowledge our ultimate aspirations.

The next step is to determine what we need to learn in order to send people safely to Mars. In other words, first work backwards from Mars.

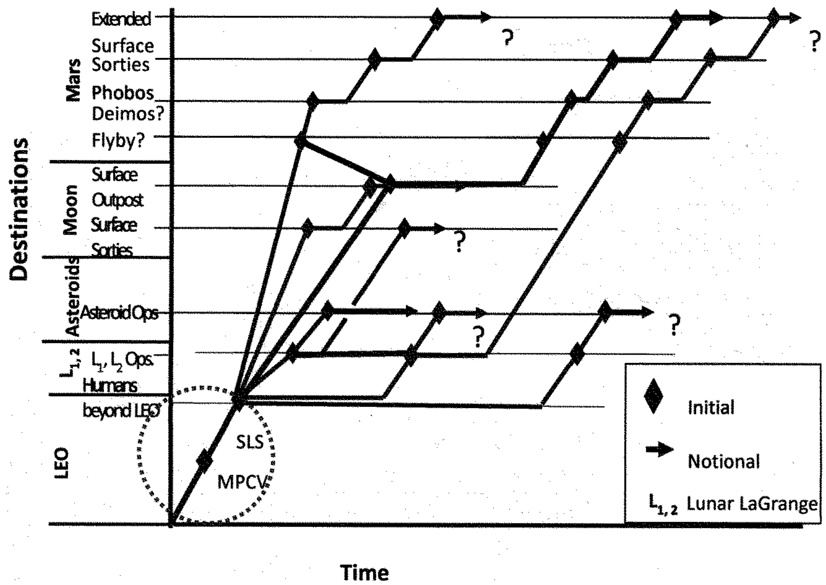
- What are the science and exploration objectives?
- What are the critical technologies and capabilities needed for travel to Mars and back?
- What are the human frailties and how do we address them?
- What are the environments we will encounter and how do we protect for them?
- What performance is required of systems?
- What are the optimal destinations for testing and demonstrations to prove out capabilities and new technologies
- Which intermediate destinations produce the best potential for exploration and science return/discoveries in their own right?
- What precursors are required, including robotic and human missions, testing and potentially other programs?

Second, it is essential to develop the most logical strategy based on collaboration with international partners, with whom the United States would work to develop complementary aspirations, capabilities and needs. Solicitation of inputs and collaboration with interested stakeholders through an organized process would also be required. Decision makers would thus become better informed and better able to assemble important mission objectives, and envision greater potential for achievements at each potential destination. These objectives would be solicited from stakeholders, including the science community (all disciplines), applied science experts, Congress, the Administration, exploration advocates and experts, academia, international partners, private industry, media, education specialists, public affairs experts, etc. If leaders were aware of the entire spectrum of possible objectives, missions could be designed to be more effective, by satisfying as many important objectives as practical. Based on this process, options would then be developed for mission sequences to destinations; options, which most effectively address the established needs, goals and objectives. This consultative process would likely result in more widespread advocacy for the strategy by enabling a broad spectrum of stakeholders to be a part of the process as they provide valued input into key mission decisions.

Third, it is important develop a long term-budget strategy for the United States' human space flight exploration plan. In my view, the budget strategy should not initially be tied strictly to dates for missions, since the timeline for some intermediate missions and human Mars missions extend too far beyond a near-term 5 year budget run-out, thereby making budget projections unrealistic and subject to criticisms of "cost growth" in later years. NASA programs, even internal to NASA, are often forced to make such unrealistic budget estimates. These complex developments are "rocket science." Inevitably technical unknowns are discovered and the programs are forced to develop alternatives – usually with success, but frequently with "cost growth". More importantly, budget instability, including budget cuts cause the development schedules to slip, which can contribute to significant "cost growth." We have seen these factors affect overall cost and schedule too often in the past. Instead, a better approach is to evaluate NASA long-term budget priorities, including evolution and completion of programs to get a sense of how to proceed. There is a tendency to continue programs, because they have momentum and constituency. However, for progress to be made on the long-term path, decisions have to be made to end programs when they reach a point of diminishing returns in achieving planned objectives. This is necessary to free funds for the important next steps on the exploration path. This needs to be accounted for in planning.

Finally, based on the shorter budget horizon of five years, the United States must rank order its mission objective priorities, choosing only those missions which contribute most effectively to the nation's long-term strategy goals. Considering both the look-back from Mars and the near-term path forward, the United States must choose a preferred path through a series of missions and destinations that most effectively address the nation's agreed-upon exploration goals and objectives. In executing this strategy, NASA must take advantage of existing capabilities (Examples: ISS, SLS, Orion, applicable science mission developments and operational approaches), as well as existing technologies if practical. NASA should not lock-in every possible new technology, instead concentrating on developing the most enabling technologies. Like the Mars Science Program, the human space flight strategy should be flexible with the anticipation that it should be driven by exploration and science discoveries as well as budget realities and emerging technologies.

The figure below updated in my recent testimony illustrates notional decision paths that could be options in this process. A key point is that the heavy-lift SLS and the long-duration Orion MPCV are necessary capabilities, regardless of the path that is ultimately taken.



Destinations
Mars
Extended
Surface
Sorties
Phobos
Deimos?
Flyby?
Moon
Surface
Outpost
Surface
Sorties
Asteroids
Asteroid Ops
?
?
?
?
$L_{1,2}$
L_1, L_2 Ops.
Humans
beyond LEO
LEO
SLS
MPCV
Initial
Notional
$L_{1,2}$ Lunar LaGrange
Time