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AUDIT OF NASA'S DEVELOPMENT OF ITS MOBILE LAUNCHERS

March 17, 2020

Report No. IG-20-013

Office of Inspector General

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Results in Brief

Audit of NASA's Development of Its Mobile Launchers

March 17, 2020 IG-20-013 (A-18-008-01)

Why We Performed This Audit

In May 2019, NASA announced the Artemis program with the goal to return U.S. astronauts to the Moon by 2024 using the Space Launch System (SLS), the Agency's new heavy-lift rocket. The Agency is developing two mobile launchers at Kennedy Space Center that will serve as the ground structure to assemble, process, transport, and launch the SLS.

The first mobile launcher (ML-1)—originally constructed in 2010 for the since-cancelled Constellation Program's Ares I launch vehicle at a cost of $234 million—required large-scale modifications to support the SLS. In addition to being bigger, more powerful, and much heavier than Ares I, the SLS employs a different rocket configuration: the SLS includes two Solid Rocket Boosters side-mounted to a Core Stage while the Ares I rocket was an in-line, two-stage rocket. After nearly a decade of development, ML-1 is nearing completion in support of the launch of Artemis I, the first integrated, uncrewed flight test of the SLS and the Orion Multi-Purpose Crew Vehicle (Orion). NASA currently plans to utilize ML-1 to launch Artemis I, Artemis II, Artemis III, and possibly a science mission to a moon of Jupiter. The Agency is also developing a second mobile launcher (ML-2) for future, larger variants of the SLS. NASA's Human Exploration and Operations Mission Directorate oversees the development of ML-1 and ML-2 as part of its Exploration Ground Systems (EGS) Program.

This audit assessed the Agency's development of its mobile launchers. Specifically, we examined whether NASA has (1) met cost, schedule, and performance goals in readying ML-1 for launching Artemis I and (2) incorporated best practices and lessons learned from the development of ML-1 into the development of ML-2. To complete this work, we interviewed EGS and other NASA personnel and representatives from contractors constructing the mobile launchers. We also reviewed federal, NASA, and EGS criteria, policies and procedures, supporting documentation, prior audit reports, and other documents related to the construction of ML-1 and ML-2.

What We Found

NASA has greatly exceeded its cost and schedule targets in developing ML-1. As of January 2020, modification of ML-1 to accommodate the SLS has cost $693 million—$308 million more than the Agency's March 2014 budget estimate—and is running more than 3 years behind schedule. Looking ahead, the project faces a risk of further cost increases and schedule slippage as ML-1 completes testing for Artemis I and undergoes modifications for Artemis II. The Agency's acquisition approach for ML-1, which lacked coordination and competition with design contractors, coupled with immature SLS requirements resulted in design errors and integration challenges that drove the project's cost increases and schedule delays. Specifically, the ML-1 project experienced numerous design errors during the outfitting of the tower that resulted in cabling and structural conflicts, equipment that did not work as intended, and issues with fabrication of the connections known as umbilicals that provide power, communications, oxygen, and fuel. NASA exacerbated these issues by accepting unproven and untested designs from one of the project's contractors. Additionally, immature SLS requirements resulted in integration challenges that also contributed to increased costs and caused schedule delays. As a result of these issues, NASA incurred substantial unplanned costs for a system the Agency currently plans to use for three or four missions.

Looking to ML-2, NASA has taken positive steps to address lessons learned from the design and development of ML-1. Specifically, NASA is utilizing a single contract to both design and build ML-2 that the Agency believes will remedy a majority of the communication and integration issues that occurred during modification of ML-1. Under such a contract, the Agency expects to better facilitate builder involvement during design; utilize a single, integrated 3D model of ML-2 that should improve communication of requirement changes; enable the contractor to suggest commercial best practices; improve monitoring of vehicle loads requirements; and require fewer parts to be designed and built by NASA for the contractor to install.

Despite these positive steps, NASA is missing opportunities to improve project management and oversight of the $486 million ML-2 project. First, the ML-2 schedule is risky due to expected vehicle load and interface requirements changes for the Orion and later variations of the SLS with already limited time for testing that could be further impacted by development delays. Second, the ML-2's design-build contract structure utilizes award fees, which if implemented similar to the ML-1 project may limit the Agency's ability to motivate the ML-2 contractor to improve performance and control costs. Finally, NASA's approach to managing the ML-2 project lacks key project management requirements that would provide greater levels of oversight and transparency. At the time of our audit, the ML-2 project had not finalized plans to (1) conduct life-cycle and milestone reviews with NASA's senior management separate from the EGS Program, limiting the Agency's ability to make timely adjustments to a project that has significant risk of cost and schedule increases, or (2) establish a project-specific Agency Baseline Commitment, limiting project visibility and NASA's ability to make adjustments prior to providing additional funding. Without greater transparency into the project's progress, it will be difficult for Agency officials and members of Congress to make informed decisions about the development of dependent programs, funding priorities, and upcoming missions.

WHAT WE RECOMMENDED

To improve potential outcomes for ML-2 development, we made four recommendations to NASA's Associate Administrator for Human Exploration and Operations Mission Directorate: (1) identify immature vehicle load and interface requirements for the ML-2 project and coordinate with appropriate offices to mitigate cost and schedule risks, (2) develop a process to ensure contractor performance ratings and related award fees for the ML-2 contract are consistent with established criteria and project outcomes, (3) ensure life-cycle and milestone reviews incorporate programmatic and technical risks and are conducted with the Associate Administrator for Human Exploration and Operations Mission Directorate and other senior Agency officials, and (4) require the ML-2 project to develop an Agency Baseline Commitment separate from the EGS Program.

We provided a draft of this report to NASA management who concurred with these recommendations and described their planned remedial actions. We consider the proposed actions responsive and will close the recommendations upon completion and verification.

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Acronyms

ABC	Agency Baseline Commitment
ASAP	Aerospace Safety Advisory Panel
EGS	Exploration Ground Systems
EUS	Exploration Upper Stage
GAO	Government Accountability Office
GFE	government furnished equipment
MEV&V	Multi-Element Verification and Validation
ML-1	Mobile Launcher 1
ML-2	Mobile Launcher 2
NPR	NASA Procedural Requirement
OIG	Office of Inspector General
RS&H	Reynolds Smith & Hills
SLS	Space Launch System
SM-1	Science Mission-1
VAB	Vehicle Assembly Building

INTRODUCTION

Human exploration of Mars has been a long-term goal of the United States for the past five decades. In May 2019, NASA announced the Artemis program with the goal of returning astronauts to the Moon by 2024 as part of its broader objective to land humans on Mars. Key to these efforts is the development of the Space Launch System (SLS)—a two-stage, heavy-lift rocket that will launch the Orion Multi-Purpose Crew Vehicle (Orion) into space.[1] NASA is also in the process of developing two mobile launchers at Kennedy Space Center (Kennedy) in Florida that will serve as the ground structure to assemble, process, transport, and launch the integrated SLS/Orion system. Collectively, these efforts represent the largest development of space flight capabilities NASA has attempted since the first Space Shuttle was produced nearly 40 years ago.

The first mobile launcher (ML-1) was originally constructed in 2010 for the since-cancelled Constellation Program's Ares I launch vehicle and required large-scale modifications to support the SLS. After nearly a decade of development at a cost of at least $927 million—$234 million for the development of the original Ares I mobile launcher base and tower and $693 million for SLS-related design and modification projects—ML-1 is nearing completion to play its part in the launch of Artemis I, the first integrated, uncrewed flight test of the SLS/Orion system.[2] NASA is also developing a second mobile launcher (ML-2) for future, larger variants of the SLS. NASA's Human Exploration and Operations Mission Directorate oversees the development of ML-1 and ML-2 as part of its Exploration Ground Systems (EGS) program.

As part of a series of audits examining aspects of NASA's human exploration efforts, we assessed the Agency's development of its mobile launchers. Specifically, we examined whether NASA has (1) met cost, schedule, and performance goals in readying ML-1 for launching Artemis I and (2) incorporated best practices and lessons learned from the development of ML-1 into the development of ML-2. See Appendix A for details on the audit's scope and methodology.

Background

Since the 1960s, NASA has utilized mobile launch platforms to support the assembly, transport, and launch of the Agency's space vehicles. These platforms enable NASA to assemble and process launch vehicles in Kennedy's massive Vehicle Assembly Building (VAB) before moving them to Launch Pad 39B for launch (see Figure 1).[3] Previously used by the Apollo and Space Shuttle programs, Launch Pad 39B is being modified to accommodate ML-1 and the future ML-2.

[1] Orion consists of a crew module capable of transporting four astronauts, a service module that provides in-space propulsion and storage, and a launch abort system that can jettison the capsule to safety in the event of an anomaly during launch.

[2] In May 2019, NASA renamed SLS/Orion Exploration Missions 1 and 2 as Artemis I and Artemis II. Under the recently announced Artemis program, NASA is hoping to land astronauts on the Moon in 2024 as part of the Artemis III mission.

[3] Launch Pad 39B is a part of Kennedy's Launch Complex 39, which also includes Launch Pads 39A and 39C. Launch Pad 39A is currently leased by Space Exploration Technologies Corporation (SpaceX) to support the company's Falcon 9 and Falcon Heavy launch vehicles. Launch Pad 39C was constructed in 2015 to accommodate smaller launch vehicles.

Figure 1: Kennedy's Vehicle Assembly Building and ML-1

Source: NASA.

Note: The VAB is the large building located in the upper left corner of the photograph and ML-1 is the tall tower-like structure resting on the crawler-transporter located in the lower right corner.

History and Evolution of ML-1

Initially built for the Constellation Program, the ML-1 structure took 2 years to construct at a cost of $234 million.[4] However, in October 2010, before NASA could outfit the structure with the needed ground support equipment to make it operational, Congress stopped funding the Constellation Program, including the Ares I launch vehicle, and directed NASA to develop the SLS.[5] Congress also directed NASA to use, to the extent practicable, existing infrastructure in developing and operating the SLS, which would eventually include ML-1.

Because ML-1 was originally designed for the Ares I rocket, it required significant modifications to launch the SLS. In addition to being bigger, more powerful, and heavier than Ares I, the SLS employs a different rocket configuration: the SLS includes two Solid Rocket Boosters side-mounted to a Core Stage, while the Ares I rocket was an in-line, two-stage rocket (see Figure 2).[6] The addition of the two Solid Rocket

[4] NASA established the Constellation Program in response to the National Aeronautics and Space Administration Authorization Act of 2005, Pub. L. No. 109-155 (2005), which called for development of a crew launch vehicle, heavy launch vehicle, and crew exploration vehicle to return to the Moon and serve as a stepping-stone to future exploration of Mars and other destinations.

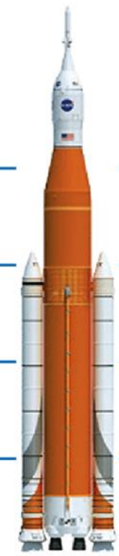
[5] National Aeronautics and Space Administration Authorization Act of 2010, Pub. L. No. 111-267 (2010).

[6] The SLS's Solid Rocket Boosters are large, segmented rocket motors with solid propellant that will provide more than 75 percent of the thrust at launch. They are attached to the Core Stage, which serves as the backbone of the rocket and includes a liquid hydrogen tank and liquid oxygen tank that hold 733,000 gallons of propellant to power the stage's four RS-25 engines needed for liftoff. The Ares I two-stage configuration was to be comprised of a single five-segment Solid Rocket Booster that would serve as the main thrust or propulsion component enabling liftoff from Earth followed by an upper stage J-2X engine that would ignite in mid-flight, propelling the launch vehicle to low Earth orbit.

Boosters necessitated modifying the exhaust port on ML-1's base from a 22-foot square to a 60-by-30-foot rectangle and strengthening supports to accommodate the SLS, which weighs almost three times as much as the Ares I.

Figure 2: Ares I Versus SLS Block 1

	ARES I	SLS Block 1
VEHICLE CONFIGURATION	In-line, two-stage rocket	Two Solid Rocket Boosters attached to a Core Stage
HEIGHT	308 feet	322 feet
WEIGHT	2 million pounds	5.75 million pounds
UPMASS	48,000 pounds to low Earth orbit	57,000 pounds to orbits beyond the Moon



Source: NASA Office of Inspector General (OIG) presentation of Agency information.

Note: NASA plans to develop three variations of the SLS: SLS Block 1, SLS Block 1B, and SLS Block 2 (see Appendix B).

To evaluate NASA's options for platforms to launch the SLS, officials at Kennedy initiated two trade studies in 2010—one conducted by NASA staff and one by a contractor.[7] Based on the results of these studies, NASA concluded that strengthening and modifying ML-1 to support the heavier weight and additional thrust of the SLS was the Agency's best option. According to NASA, not only were the necessary modifications technically feasible, but using ML-1 was the most cost-effective approach to launching SLS compared to the other options of either modifying one of the three Space Shuttle launch platforms or building a new launch platform.[8] At that time, preliminary estimates determined that modifying the ML-1 structure would cost $54 million, modifying one of the Space Shuttle platforms would cost $93 million, and constructing a new platform would cost $122 million.[9] In May 2011, Kennedy officials decided to use ML-1 to support the SLS, and the NASA Administrator concurred with the decision in June 2011.

In 2012, we examined NASA's plans for ML-1 to determine whether the Agency sufficiently evaluated all options before deciding that modifying the launcher in support of SLS was in the best interest of the government.[10] We found that NASA's decision to modify ML-1 was technically feasible and, at the time,

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7 NASA, *2011 Mobile Launcher Structure Trade Study—Initial Findings* (KSC-NE 11477, March 2011), and *2011 Mobile Launcher Structure Trade Study—Initial Findings, Volume 2, Cost Annex* (KSC-NE 11477 Volume 2, April 2011).

8 The three Space Shuttle platforms were originally designed for the Apollo Program and later modified to launch the Space Shuttle.

9 The estimates did not include the cost of outfitting the structure with ground support equipment because those costs were considered to be the same for each option.

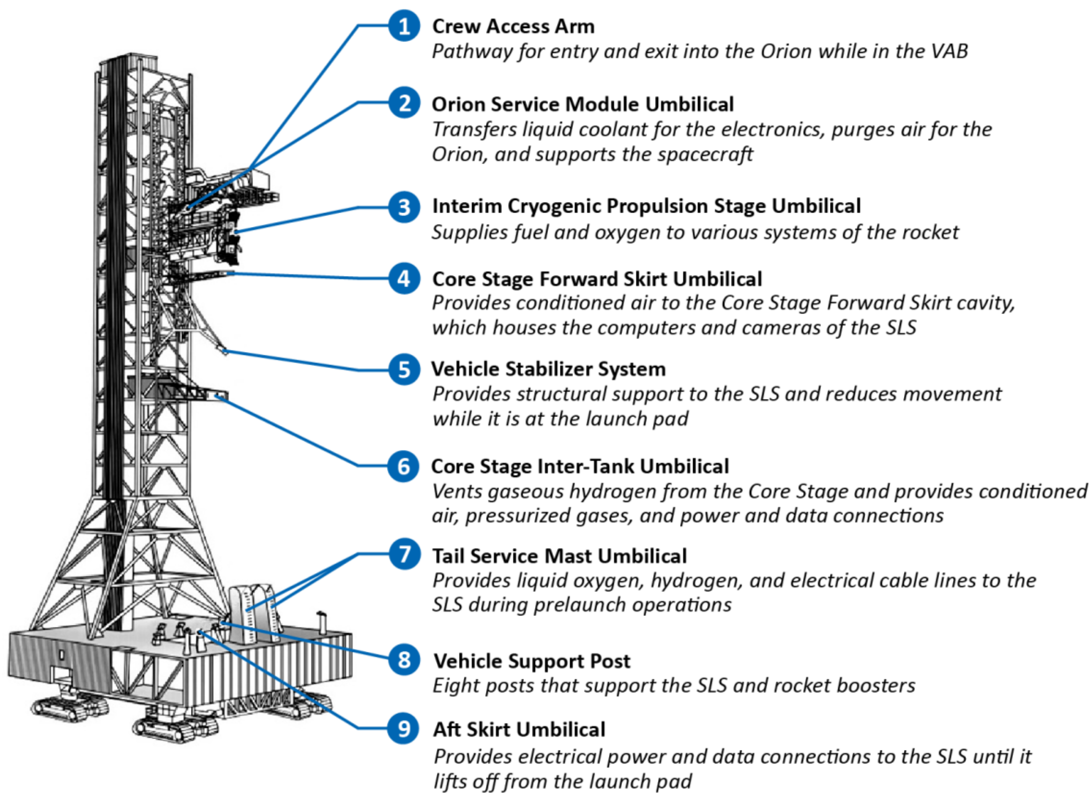
10 NASA OIG, *NASA's Plans to Modify the Ares I Mobile Launcher in Support of the Space Launch System* (IG-12-022, September 25, 2012).

the most cost-effective option for launching at least the initial versions of the SLS. However, we questioned the studies and corresponding cost estimates that NASA used to support its decision because they were based on preliminary assumptions and may not have addressed all of the challenges or costs associated with planned larger SLS versions.

ML-1 Structure and Operations

ML-1 was specifically modified to support the SLS Block 1 vehicle, which is the smallest configuration in the SLS portfolio of increasingly more powerful launch vehicles. (See Appendix B for details on the SLS configurations and the Artemis launch schedule.) The SLS Block 1 vehicle, which stands at 322 feet and weighs 5.75 million pounds, can send more than 26 metric tons, or 57,000 pounds, of crew and cargo to orbits around the Moon. As shown in Figure 3, ML-1 consists of a two-story base, 355-foot-tall launch umbilical tower, and facility ground support systems. The launch tower is equipped with several connections, called umbilicals, which will connect the integrated SLS/Orion system to the tower and provide power, communications, coolant, and fuel. Additional accessories will provide stabilization for the rocket and access to the crew or cargo capsule.

Figure 3: ML-1 Structure, Umbilicals, and Accessories



Source: NASA OIG presentation of Agency information.

During preparations for launch, the crawler-transporter—a large tracked vehicle and platform—will pick up and move ML-1 into the VAB.[11] Once ML-1 is secured in the VAB, the SLS and Orion systems will be integrated onto the launcher. The crawler-transporter will then transport ML-1 with the integrated SLS/Orion system to Launch Pad 39B. After the crawler-transporter makes its 8-hour, 4-mile trek to Launch Pad 39B, engineers will lower ML-1 onto the pad and remove the crawler-transporter. During launch, each umbilical and launch accessory will release from its connection point on the launch vehicle, allowing the integrated SLS/Orion system to liftoff from the pad. After launch, the crawler-transporter will return ML-1 to the VAB where it will be prepared for the next launch.

Crawler-Transporter 2 Traveling to Launch Pad 39B

Source: NASA.

NASA currently plans to utilize ML-1 to launch Artemis I, Artemis II, Artemis III, and possibly Science Mission-1 (SM-1). Slated to launch no earlier than November 2020, Artemis I will serve as the first uncrewed mission of the integrated SLS/Orion system to demonstrate the performance of the SLS, Orion, and ground systems, including ML-1.[12] On this mission, Orion is expected to orbit about 40,000 miles beyond the Moon. By fall of 2022, NASA expects to launch Artemis II as the first crewed launch of the integrated SLS/Orion system, which will perform an up to 21-day lunar flyby mission before returning to Earth. The Agency plans to launch Artemis III in 2024 as the first mission since the Apollo era to place humans, including the first female, on the surface of the Moon. The mission is planned for astronauts to dock with the Lunar Gateway, a small spaceship in orbit around the Moon that would enable astronauts access to the entire surface of the Moon, before descending to the Moon's surface in a lander for a nearly week long mission. Finally, Congress has directed NASA in 2025 to launch a satellite to orbit Europa, a moon of Jupiter that may contain an interior ocean that could harbor conditions suitable for life, using the SLS launch vehicle, a mission also known as SM-1.[13]

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[11] NASA spent $54 million to upgrade one of the two crawler-transporters previously used for the Apollo and Space Shuttle programs to carry the heavier loads anticipated with the SLS.

[12] As of January 2020, NASA anticipates the Artemis I launch date will slip to spring 2021.

[13] NASA was directed to use an SLS Block 1 configuration for the Europa mission by the Consolidated Appropriations Act of 2019, Pub. L. No. 116-6 (2019). In August 2019, the OIG sent a letter to Congress highlighting a series of issues related to mandating use of the SLS for the Europa mission given the priority of Artemis launches.

Contracts to Design and Build ML-1

Since 2008, NASA has utilized six major contracts to design and construct ML-1 (see Table 1).

Table 1: Major ML-1 Contracts

Contractor	Award/First Issue	Scope of Work	Contract Type	Costs as of Fiscal Year 2019 (Dollars in Millions)
Hensel Phelps	May 2008	Structure construction (as part of the Constellation Program)	Firm-fixed-price	$144.1
Vencore Services and Solutions	March 2011	Subsystem designs for ground support equipment and other fabrication and testing services	Cost-plus-award-fee	$228.0
Reynolds Smith & Hills	February 2012	Primarily developed designs for structural modifications	Firm-fixed-price	$25.0
J.P. Donovan Construction	May 2013	Structural modifications	Firm-fixed-price	$32.7
J.P. Donovan Construction	August 2015	Outfitting ground support equipment installation and construction	Firm-fixed-price	$180.7
Jacobs Technology	November 2017	Subsystem designs for ground support equipment and other fabrication and testing services	Cost-plus-award-fee	$58.2

Source: NASA OIG presentation of Agency information.

Kennedy first contracted with Hensel Phelps in May 2008 to construct ML-1's basic structure and support systems for the Ares I rocket configuration. Under this firm-fixed-price contract, Hensel Phelps supplied the labor, materials, and equipment necessary for initial construction.[14] The outfitting of ground support equipment, such as umbilicals, propellant, gases, instrumentation, controls, and communications, necessary to support the Ares I rocket were to be provided under separate contracts that were never executed because of the Constellation Program's cancellation.

In 2011, NASA began work on subsystem designs for ground support equipment needed to modify ML-1 to support the SLS. To complete the design work, Kennedy enlisted three primary contractors that already had contracts with the Center: Vencore Services and Solutions (Vencore), Jacobs Technology (Jacobs), and Reynolds Smith & Hills (RS&H). In each instance, Kennedy issued task orders—that is, orders for services from established firm-fixed-price or cost-plus-award-fee contracts the Center had established with the contractors—for engineering and institutional support.[15] Vencore was the original contractor for designing the ground support equipment to outfit ML-1 until 2017 when Kennedy chose not to renew the contract due to Vencore's overall performance. NASA transferred the remaining design and testing work to Jacobs. In November 2017, Jacobs began executing task orders for these services. Beginning in 2012, Kennedy selected RS&H to develop structural drawings and design launch mounts, structures, and some ground support equipment for the retrofitting of ML-1.

[14] A firm-fixed-price contract provides for a price that is not subject to adjustment on the basis of the contractor's cost experience in performing the contract. This contract type places maximum risk on the contractor and full responsibility for all costs and resulting profit or loss.

[15] A cost-plus-award-fee contract is a cost-reimbursement contract that provides for a fee consisting of a base amount fixed at inception of the contract and an award amount, based upon an evaluation by agency officials, sufficient to provide motivation in contract performance.

In April 2013, after initial designs of the ML-1 modifications were complete, Kennedy awarded J.P. Donovan Construction (J.P. Donovan) a firm-fixed-price contract to update ML-1 to accommodate the SLS. This contract contained the modifications necessary to create new exhaust ports and structural reinforcements designed by RS&H. Kennedy awarded J.P. Donovan a second firm-fixed-price contract in August 2015 to make modifications necessary for installing ground support equipment, which were primarily designed by Vencore but also included some structural and equipment designs by RS&H. NASA also contracted for additional services from cleaning, steel fabrication, and communications companies throughout construction and modifications to ML-1.

Decision to Develop ML-2

In October 2017, the Aerospace Safety Advisory Panel (ASAP) raised concerns about a potential 33-month gap between SLS launches due to the time required to modify ML-1 to accommodate the larger SLS variants, namely SLS Block 1B and SLS Block 2 (see Appendix B for more information), that were expected to incorporate the Exploration Upper Stage (EUS).[16] However, the use of the EUS raises the height of the SLS 30 feet and would require significant modifications to ML-1. In addition to the 33 months required for modifications, ASAP concluded that modifying ML-1 would create potential safety risks given the expected rate of attrition of Kennedy's ground and launch workforce over a 33-month inactive period, resulting in a loss of experience and knowledge. Given these concerns, ASAP recommended that NASA begin construction of ML-2 as soon as possible. Following this recommendation, Congress included $350 million in the Consolidated Appropriations Act of 2018 to construct ML-2 for SLS Block 1B and SLS Block 2.[17]

In June 2019, NASA awarded a cost-plus-award-fee, end-item contract to Bechtel National, Inc., to design and construct ML-2.[18] The contract has a total value of $383 million with Bechtel expected to complete the project in 44 months beginning in July 2019 and ending in March 2023.

Similar to ML-1, ML-2 will feature a two-story base structure along with facility ground support systems. However, ML-2 will differ from its predecessor given its nearly 400-foot service tower, which is 45-feet taller than ML-1, and different locations for umbilicals and accessories (see Figure 4). Rockets using ML-2 will undergo the same preparations for launch as ML-1, including stacking in Kennedy's VAB, transporting on the crawler-transporter, and launching from Launch Pad 39B.

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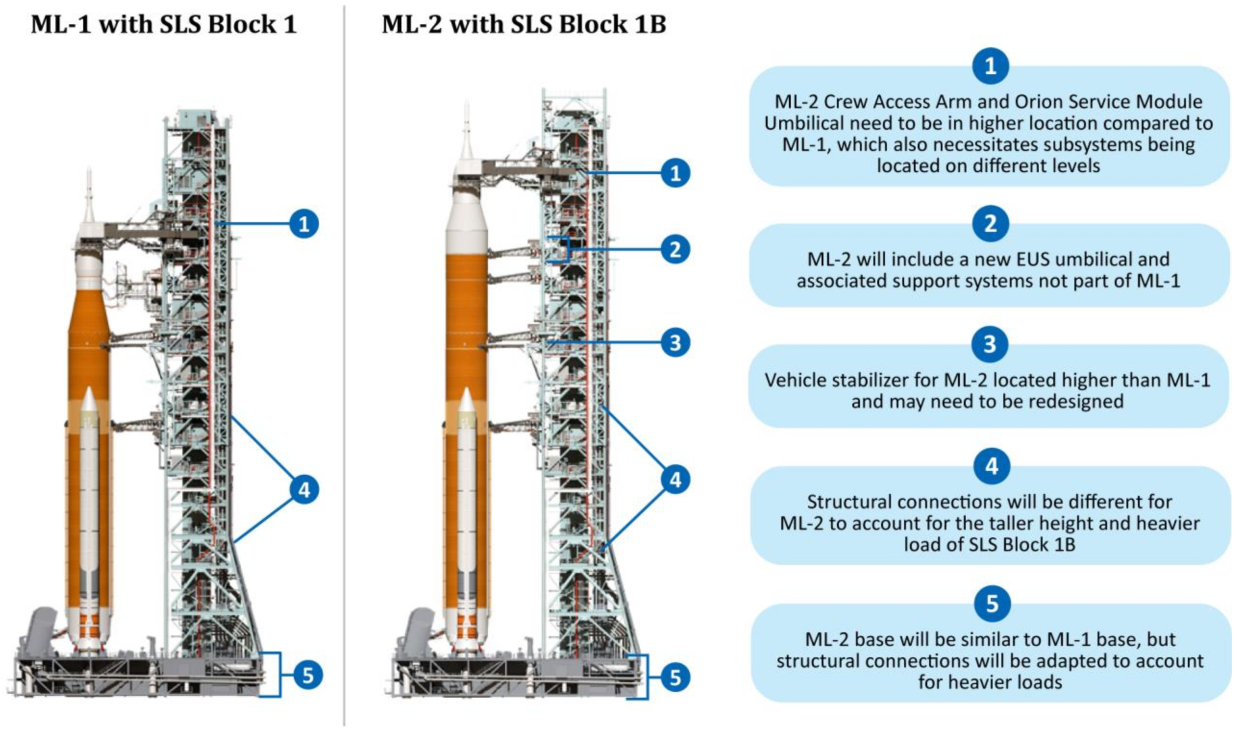
16 ASAP provides advice and makes recommendations to the NASA Administrator on matters related to aerospace safety. ASAP, *Annual Report for 2017* (January 2018). The EUS is planned to replace the interim cryogenic propulsion stage that will be used on the initial configuration of SLS for Artemis I and will be capable of carrying larger payloads.

17 Consolidated Appropriations Act of 2018, Pub. L. No. 115-141 (2018).

18 Similar to a cost-plus-award-fee contract, a cost-plus-award-fee, end-item contract is utilized when an end item is delivered and the quality of a contractor's performance cannot be measured until the end of the contract. In addition to the final evaluation, interim evaluations are conducted to monitor performance prior to contract completion, provide feedback to a contractor on the government's assessment of its performance, and establish a basis for making interim award fee payments.

Figure 4: Comparison Between ML-1 and ML-2 Concepts



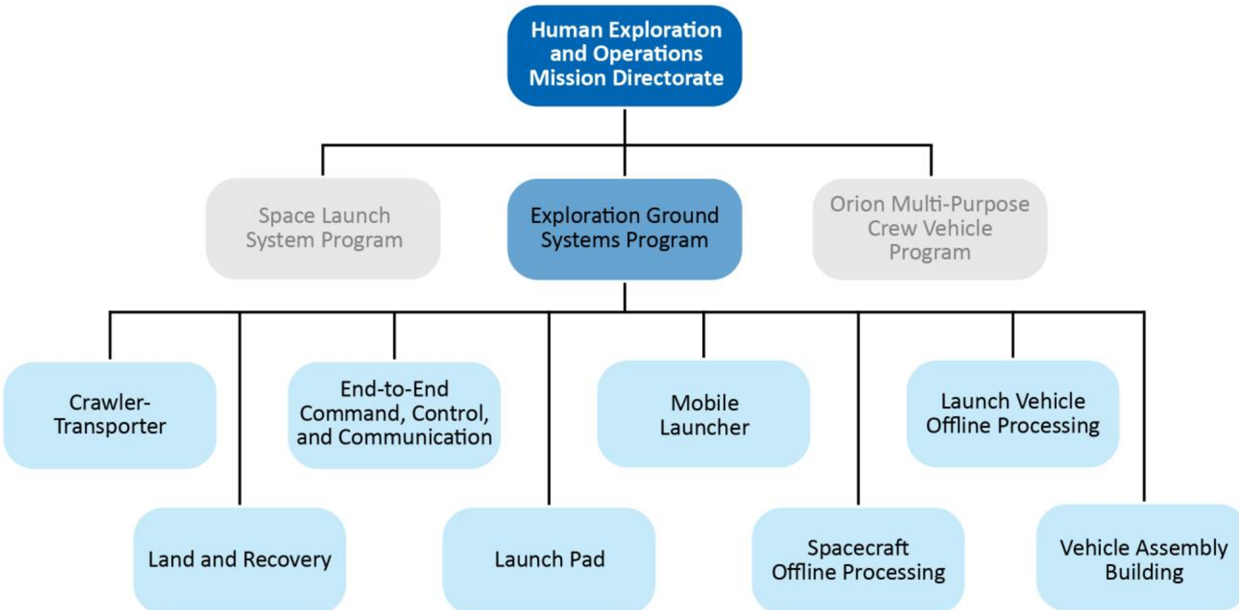
Source: NASA OIG presentation of Agency information.

NASA Program and Project Management

NASA's Human Exploration and Operations Mission Directorate generates requirements for and oversees the concurrent development of the SLS, Orion, and EGS programs (see Figure 5). The EGS Program is based at Kennedy and develops and operates the facilities necessary to assemble, transport, launch, and recover rockets and spacecraft, including ML-1 and ML-2. Previously known as the 21st Century Ground Systems Program and then the Ground Systems Development and Operations Program, the EGS Program was charged with modernizing and transforming Kennedy's Launch Complex 39 to benefit current and future NASA programs along with other emerging users, including commercial companies. NASA classified EGS as a single-project program—that is, a program that features a long development and operational lifetime and represents a large investment of Agency resources, including contributions from multiple organizations.[19] The EGS Program is comprised of multiple elements that provide development and operational products in support of SLS and Orion (see Figure 5). The Mobile Launcher element is responsible for the design, development, build, hardware/software integration, verification and validation, test, and transition to operations for ML-1 and ML-2.

[19] NASA Procedural Requirement 7120.5E, *NASA Space Flight Program and Project Management Requirements w/Changes 1-16* (August 14, 2012).

Figure 5: Elements of Exploration Ground Systems Program



Source: NASA OIG presentation of Agency information.

Modifying ML-1 is Costing Significantly More and Taking Considerably Longer than Planned

NASA has greatly exceeded its cost and schedule targets in developing ML-1. As of January 2020, the ML-1 modification project to accommodate SLS has cost $693 million—$308 million more than the Agency's March 2014 budget estimate—and is running over 3 years behind schedule. Looking ahead, the project faces a risk of further cost and schedule slippage as ML-1 completes testing for Artemis I and undergoes modifications for Artemis II. The Agency's acquisition approach for the launch platform, which lacked coordination and competition with design contractors, coupled with immature SLS requirements resulted in design errors and integration challenges that drove the project's cost increases and schedule delays.[20] As a result, NASA incurred substantial unplanned costs for a system that the Agency currently plans to use for three or four missions.

NASA Significantly Exceeded Cost and Schedule Goals in Developing ML-1

As of January 2020, NASA plans to spend $693 million to modify ML-1 to accommodate the SLS for Artemis I and Artemis II, $308 million more and over 3 years later than its March 2014 estimate. As an element of the larger EGS Program, the ML-1 project estimated in March 2014 that after having already spent $211 million, the remaining cost to modify ML-1 would be $174 million with the work taking 3 years to complete. Since that time, the Agency has adjusted the project's budget and timetable each year as the Artemis I launch date has slipped and additional costs and schedule were required to complete the ML-1 project. Collectively, these additional costs amounted to $277.3 million and an expected completion date for ML-1 in April 2020. Although the 2014 estimate originally contained funding for both Artemis I and Artemis II modifications, as costs increased and the schedule slipped NASA postponed some of the modifications necessary to support Artemis II.[21] Consequently, the launcher modifications for Artemis II are now expected to be completed by 2022 at an estimated additional cost of $30.6 million.

Table 2 details the Agency's cost and schedule assumptions by year beginning with the budget estimate established in 2014 and subsequent yearly adjustments.

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[20] For the purposes of this report, we are considering design errors to include designs that did not work as intended, were incomplete, or conflicted with other designs.

[21] The most significant modifications for Artemis II relate to an emergency egress system needed to evacuate crew off the tower in the event of an anomaly.

Table 2: Cost and Budget Estimates to Modify ML-1

Date	Planned Artemis I Launch Date	Fiscal Year (Dollars in Millions)										
		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
March 2014	December 2017	$13.9	$34.2	$93.0	$69.6	$73.9	$63.6	$20.0	$16.5	$0.0	$0.0	**$384.7**
June 2015	September 2018	13.9	34.2	93.0	69.6	70.5	63.6	20.0	16.5	0.0	0.0	**$381.3**
August 2016	November 2018	13.9	34.2	93.0	69.6	85.5	86.5	55.2	17.0	0.0	0.0	**$454.9**
October 2017	December 2019	13.9	34.2	93.0	69.6	85.5	90.4	127.8	55.0	0.0	0.0	**$569.6**
September 2018	June 2020	13.9	34.2	93.0	69.6	85.5	90.4	127.8	81.2	0.0	0.0	**$595.6**
March 2019	June 2020	13.9	34.2	93.0	69.6	85.5	90.4	127.8	84.2	46.3	0.0	**$644.9**
January 2020	November 2020	13.9	34.2	93.0	69.6	85.5	90.4	127.8	84.2	61.8	1.6	**$662.2**
Work to be performed in fiscal years 2020 through 2022 to complete the modifications for Artemis II												**$30.6**
Total costs as of January 2020[a]												**$692.8**

Source: NASA OIG analysis of Kennedy Office of the Chief Financial Officer data.

Note: Gray highlighted data are budget projections provided by the Kennedy Office of the Chief Financial Officer.

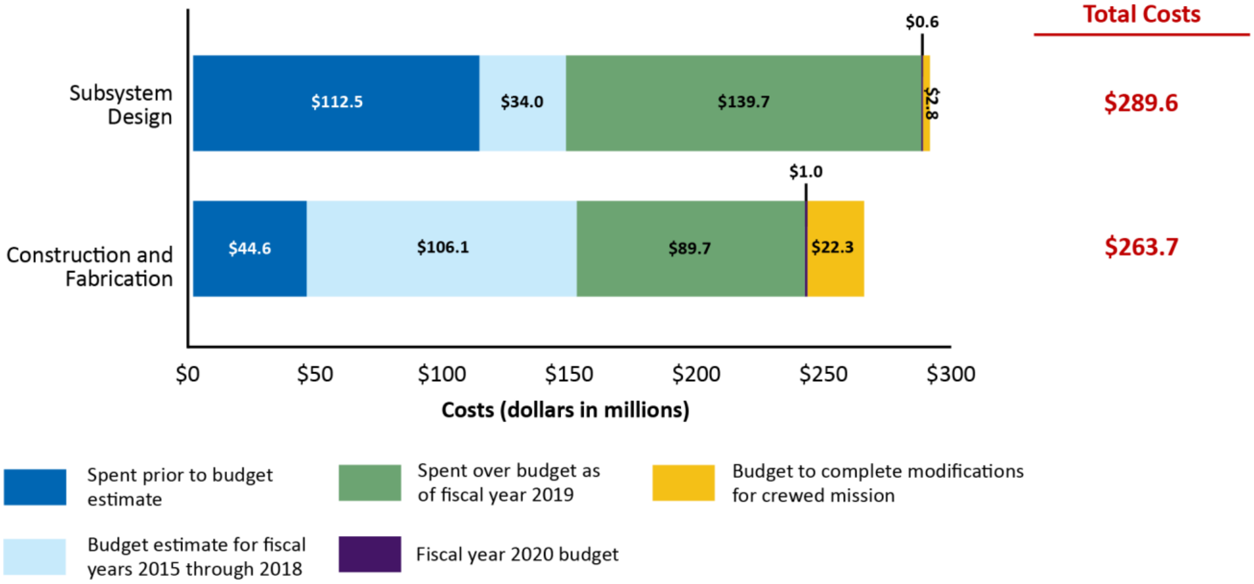
[a] NASA originally spent $234 million to build the Ares 1 mobile launch structure that subsequently has been modified to accommodate the SLS launch vehicle.

Design and Construction Problems Drove ML-1's Cost and Schedule Increases

Unanticipated design and construction problems were the primary drivers behind the ML-1 project's cost and schedule increases. As of January 2020, NASA planned to spend $289.6 million to complete the subsystem designs for ML-1, $143.1 million more than the Agency had estimated it would cost in its 2014 budget estimate. Similarly, NASA's costs for construction and fabrication of ML-1 were estimated at $150.7 million in the 2014 estimate but have grown by $113 million to $263.7 million as of January 2020. Figure 6 shows NASA's costs for subsystem design work and construction prior to the 2014 budget estimate, projected costs at the 2014 budget estimate, amounts spent over budget through fiscal year 2019, planned expenditures for fiscal year 2020, and planned expenditures to complete modifications for Artemis II.[22]

[22] This amount does not include $139.5 million in costs for NASA's civil servant labor, structural designs, operations planning and documentation, and other miscellaneous activities such as cleaning, inspections, spare parts, and software.

Figure 6: Design and Construction Costs to Modify ML-1



Source: NASA OIG analysis of Agency financial data.

Subsystem Design Contracts

Subsystem design work was conducted under two cost-plus engineering services contracts with Vencore from 2011 through 2017 and Jacobs since December 2017. In March 2011, NASA used three cost-plus-award-fee task orders to draw funds from the contract to have Vencore provide engineering, technician, project management, and other support services to design SLS-specific ground support equipment for ML-1.[23] According to NASA personnel, even though SLS requirements were still being developed, Vencore was focused on developing ground support elements that would be needed by any vehicle designed to launch from ML-1. As such, the task orders focused on changing hardware designs developed for Ares I to support the SLS. Between fiscal years 2011 and 2014, NASA spent approximately $112.5 million on the subsystem design task orders with Vencore.

When NASA established the initial budget estimate in March 2014, the ML-1 project office planned to spend an additional $34 million to complete the outfitting designs. However, as of January 2020, the Agency had revised that estimate to $177.1 million, a more than 420 percent increase over the initial budget projection.

In December 2017, after Vencore's contract was set to end, Kennedy transferred the subsystem design work responsibilities to Jacobs. According to Kennedy officials, NASA chose to not exercise Vencore's final contract year option in 2017 due to Vencore's overall performance. These issues were identified in a 2016 NASA OIG report.[24] As of the end of the Vencore contract, NASA had accepted/deemed most of the initial design work as complete. As such, Jacobs' primary responsibility was to finalize the design products and make any necessary corrections to the designs as issues were identified during

[23] The three task orders were organized by technical subjects: electrical, fluids, and mechanical. Starting in 2013, NASA implemented four additional design task orders to support testing, access, and additional manpower needed to complete the ML-1 project.

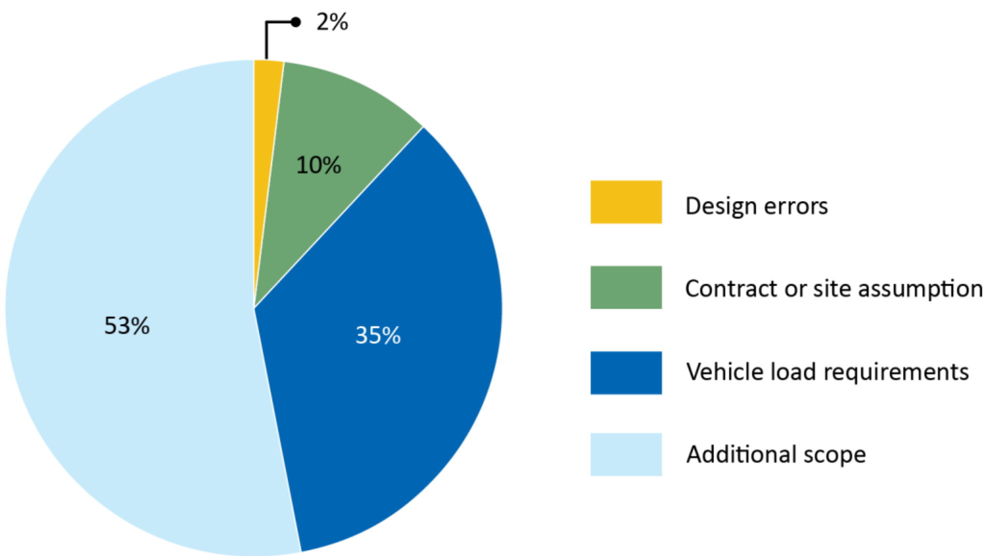
[24] NASA OIG, *Audit of NASA's Engineering Services Contract at Kennedy Space Center* (IG-16-017, May 5, 2016).

construction and testing. To this end, significant additional work was required to modify the designs and respond to questions from the construction contractor (discussed below). As of January 2020, the Agency expected to spend an additional $2.8 million to complete design work, bringing the total cost for the subsystem designs to $289.6 million.

Structural Modifications Construction Contract

In May 2013, NASA awarded a firm-fixed-price contract (heretofore referred to as the "structural construction contract") to J.P. Donovan to modify the ML-1 originally built for the Ares I to create new exhaust holes and structural reinforcements to accommodate the larger SLS vehicle. Valued at $20.8 million, this work was expected to take just over 1.5 years to complete. However, at the time of the contract's completion in 2015, costs had increased to $32.7 million (a 58 percent increase) and the work took an extra 9 months to complete. According to our analysis, these cost and schedule increases were mostly a result of SLS vehicle requirement changes and additions to the project's scope. Specifically, as shown in Figure 7, two items were the major cost drivers: new SLS load requirements that added $4.3 million in costs and a known requirement that was not included in the original contract to add new floors to the tower that added an additional $6.3 million.[25] The additional floors in the launcher were to provide crew access to the launch vehicle, but the costs were not included in the original contract because the designs were not ready at contract award. To a lesser extent, we also identified that changes to contract and site assumptions increased costs by $1.1 million and design errors by another $290,000.[26]

Figure 7: Source of Structural Construction Contract Cost Increases



Source: NASA OIG analysis of structural construction contract modifications, as of March 2019.

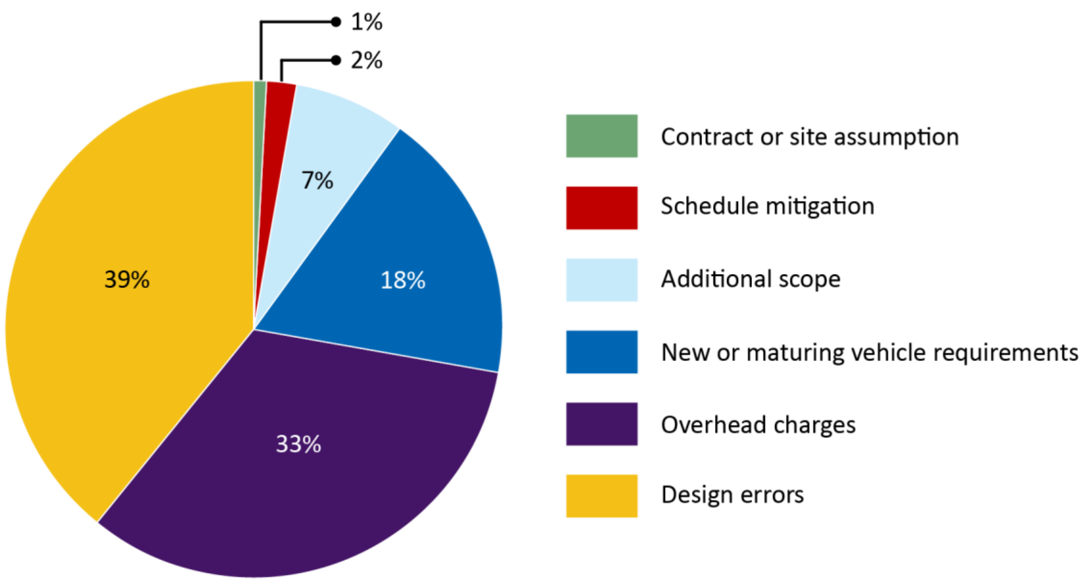
[25] Load requirements are the requirements for ML-1 to support the loads created by the SLS during all phases of its service life, including assembly and transportation to the launch pad, environmental impacts such as winds, umbilicals, test firing, and liftoff.

[26] Contract and site assumptions are specific items covered in the contract on which the contractor relies and assumes to be true. Changes can occur when the assumption turns out not to be true, increasing the cost of the contract. For example, NASA intended to provide power to the contractor on the construction site; however, the electrical panel was inoperable and needed replaced, adding costs to the contract.

Ground Support Equipment Outfitting Construction Contract

In August 2015, NASA awarded a firm-fixed-price contract (heretofore referred to as the outfitting construction contract) to J.P. Donovan to outfit the ML-1 structure with the needed equipment and infrastructure to support the SLS. Initially valued at $45.8 million, this work was expected to take 1.25 years to complete. However, as of March 2019, the contract had risen to $168 million (a 267 percent increase) and the work was not expected to be completed until April 2020 (over 3 years later). As shown in Figure 8, the contract experienced significant cost and schedule increases due mostly to outfitting design errors and new or maturing SLS requirements. Specifically, according to our analysis, redoing work to correct design errors increased costs by $48 million, while new or maturing SLS requirements added $21.9 million. As a result of these design errors and changing requirements, Kennedy had to extend the duration of the contract. In addition to the costs for design error corrections and changing requirements, this extension added $41.8 million for overhead charges and other expenses such as schedule mitigation related to additional overtime hours; additional costs related to longer rental periods for cranes, vehicles, welding tools, and heavy equipment; and retaining nonsupervisory foremen for safety, quality, and other administrative tasks. We also identified $8.8 million in additional funding that was used to add new scope to purchase long-lead time items such as cabling and to build scaffolding to access the launch vehicle in the VAB.[27] Finally, $1.6 million in additional funding was added as a result of changes in contract or site assumptions, mainly to maintain the elevator on ML-1, which sustained heavy use during construction.

Figure 8: Source of Outfitting Construction Contract Cost Increases



Source: NASA OIG analysis of outfitting construction contract modifications, as of March 2019.

[27] Long-lead-time items are products that, because of the time it takes to create and deliver, take additional time once ordered.

Additional Cost and Schedule Risks Remain for ML-1

Looking ahead, the risk of additional cost increases and schedule delays exist as ML-1 completes Multi-Element Verification and Validation (MEV&V) testing for Artemis I and undergoes modifications for Artemis II. Since September 2018, EGS has been conducting MEV&V testing on ML-1—a phase that provides the Agency an opportunity to ensure that systems such as the umbilicals are safe and work as intended. Originally expected to be completed in July 2019, MEV&V testing has occurred in two phases: first at the VAB and then at the launch pad. In June 2019, NASA moved ML-1 to the launch pad to begin the second phase of testing even though first phase testing in the VAB was not completed due to technical issues with the umbilicals. The delays were further exacerbated by a government shutdown from December 2018 to January 2019 and weather events. The majority of MEV&V testing was completed by the end of January 2020.[28] However, issues were identified with the ground cooling system and vehicle stabilizer, which need to be addressed and retested. In addition, throughout MEV&V, the ML-1 project has been concurrently conducting construction activities, such as the fueling system for the SLS and structural load reinforcement, in order to finish equipment outfitting. As a result, NASA officials said they had to retest equipment previously certified because adjoining systems were modified during the construction process, which further slowed MEV&V activities.

NASA's Acquisition Strategy and Changing SLS Requirements Caused Significant Design Issues for ML-1

NASA's acquisition strategy for ML-1 did not provide for effective coordination among the various design activities and failed to initially identify a design contractor that specialized in large, complex construction projects. Although design errors are to be expected in a project of this size and complexity, the amount and associated costs for design modifications for ML-1 could have been reduced. In addition, immature or undefined SLS and Orion requirements also caused numerous design changes. The ML-1 project experienced numerous design errors during the outfitting of the tower that resulted in cabling and structural design conflicts, equipment that did not work as intended, and issues with the fabrication of the umbilicals. NASA exacerbated these issues by accepting unproven and untested designs from Vencore in order to advance the construction and fabrication contracts. Agency personnel stated that at times they knew the subsystem designs were not complete or needed more testing but advanced them because the project schedule required it so fabrication and construction activities could continue. However, by accepting incomplete subsystem designs, the Agency ultimately experienced significant delays and costly rework for the ML-1 project, which in turn created further delays and cost overruns.

[28] The costs associated with MEV&V activities are tracked at the EGS program level because the testing integrates multiple launch elements. As such, those costs were not included in our analysis.

NASA Lacked Design Coordination

NASA used multiple design contractors to modify the ML-1 who failed to effectively coordinate their individual design changes, and the Agency had no comprehensive process to incorporate work from the different contractors into a single master design. NASA used RS&H for structural designs, while Vencore and later Jacobs were utilized to support the ML-1 project with subsystem designers to develop plans for the equipment and infrastructure to support the SLS. According to project personnel, RS&H's design changes were not consistently incorporated into the designs that Vencore subsequently used, which caused problems during construction when the ML-1 structure did not match Vencore's subsystem designs.

We found that NASA did not effectively communicate internally when developing different designs, primarily electrical, fluids, and mechanical subsystems. According to Kennedy personnel, these three developmental teams supported by Vencore personnel did not communicate design changes well with each other. As a result, J.P. Donovan, the construction contractor, experienced problems with the subsystem designs and had to stop work and request direction from Vencore to resolve various design inconsistencies. For example, NASA spent an additional $1.8 million to move and redesign supports for cryogenic piping that was in the way of environmental control system ducting and to move umbilical hydraulic piping to mitigate fluid leaks. Furthermore, Jacobs personnel stated that as a result of Vencore's weak coordination early on in the project, they were not able to complete a master engineering design for ML-1. This could impact ML-1 operations if NASA needs to refer back to the designs to resolve technical issues related to supporting the SLS. Further, the lack of a single master design could impact ML-2 construction if the new contractor intends to rely on the ML-1 design as a basis to develop ML-2 designs. As of October 2019, the accuracy of the single master plan for ML-1 was questionable.

NASA Could Have Benefited from Additional Competition when Selecting the Subsystem Design Contractor

Instead of using the solicitation process to identify the most qualified contractor for the subsystem design duties, NASA used Vencore, an in-house, prequalified engineering services contractor that performed a range of services at Kennedy from laboratory and shop maintenance to engineering activities such as software development. According to Kennedy Program officials, Vencore was selected to support the development of the ML-1 subsystem designs in March 2011 because they provided the most flexibility and affordability. Although utilizing Vencore did provide flexibility, the costs for the ML-1 subsystem design work increased significantly. Furthermore, Vencore and NASA had been working on the ML-1 subsystem designs since March 2011 and the Agency did not award the outfitting construction contract until August 2015. As such, there appears to have been enough time for NASA to issue a new solicitation and competition to identify the best suited contractor to complete this complex and difficult subsystem design.

We also found that Vencore's significant employee turnover during the project contributed to its design errors and slow response when correcting mistakes. According to NASA personnel, Vencore had difficulty retaining design personnel because of the competitive aerospace job market at Kennedy. The lack of a stable workforce resulted in slow response times by the contractor as they were forced to answer questions from the other contractors while proceeding with work that was already planned. Additionally, Vencore relied on a limited number of subject matter experts to answer construction questions. According to NASA officials, as those experts left, Vencore's response times increased even further. Jacobs personnel said they experienced many of the same issues when they took over

Vencore's design duties in December 2017 and had to hire many of the same personnel that previously worked for Vencore as well as hiring staff from out of state to meet contract requirements. In our judgement, given the complexity and scope of the subsystem design work, wide competition through the use of the bid solicitation process would have substantially benefited the project.

Immature SLS and Orion Requirements Resulted in Costly Design Changes for ML-1

Although the subsystems being developed were highly complex, immature or undefined SLS and Orion requirements caused numerous design changes for ML-1, which in turn increased the project's cost and schedule. Specifically, NASA's finalization of requirements late in the development cycle resulted in significant rework of the ML-1 structure and key components such as the umbilicals that interface with SLS and Orion. We determined that requirement changes caused costs for the outfitting construction contract to increase by at least $21.9 million and caused schedule delays that are difficult to quantify.[29] For example, vehicle load requirements from the SLS Program were not fully established until after the outfitting construction contract was awarded in August 2015. NASA officials could not explain why the delay occurred but agreed that the ML-1 project should have acted sooner than it did. As a result, in 2018 and 2019, NASA made structural modifications to ML-1 that added $6 million in additional costs. SLS and Orion requirement changes also resulted in ML-1 design changes for launch accessories and umbilicals, including the Vehicle Stabilizer system that supports the SLS and reduces movement, Tail Service Mast Umbilical that provides various commodities to SLS, Interim Cryogenic Propulsion Stage Umbilical that also provides commodities to SLS, and Crew Access Arm peripherals that provide a pathway for crew to board the Orion capsule.[30]

[29] NASA separated contract modifications for cost and schedule, making it difficult to link specific cost increases to schedule increases; however, delays to the overall schedule resulted from the requirement changes.

[30] Commodities include electricity, fuel, oxygen, communications, or other resources needed by SLS or crew while on the launch pad.

NASA Taking Steps to Incorporate Lessons Learned for ML-2 Development, but Missing Opportunities to Improve Project Management and Oversight

NASA has taken positive steps to address lessons learned related to the design and development of ML-1, but we found the Agency is missing opportunities to increase performance for development of the $486 million ML-2 given its decisions related to the project's schedule, contract structure, and management approach that lack key requirements to enable additional oversight. Without greater transparency into the project's progress, it will be difficult for Agency officials and members of Congress to make informed decisions about the development of dependent programs, funding priorities, and upcoming missions.

ML-2 Design-Build Contract Expected to Address Many ML-1 Integration Issues

After NASA decided in March 2018 to build a second mobile launcher for the more powerful versions of the SLS, Kennedy officials began the process of researching lessons learned from the ML-1 development project, such as the lack of an integrated design process and the improper characterization and maintenance of loads data. Ultimately, they determined that utilizing a single contract to both design and build ML-2 would likely remedy a majority of the communication and integration issues that occurred with the ML-1 project. In June 2019, NASA awarded a cost-plus-award-fee, end-item contract to Bechtel National, Inc., to design and construct ML-2. The contract has a total value of approximately $383 million and Bechtel is expected to complete the project within 44 months or by March 2023. The contract includes provisions to convert to a firm-fixed-price contract once the design is 90 percent complete.

A design-build contract is a method in which NASA contracts with one organization for both project design and construction. An end-item award fee allows the Agency to pay interim sums of money known as award fees as a reward for good performance based on semiannual evaluations during the contract period. The end-item award fee requires a final evaluation and adjustment after the project is complete to determine the total amount of money in additional award fees the contractor will be paid for exceptional performance, as defined in the contract. Bechtel can hire subcontractors as needed, but the company remains responsible for both design and construction issues for the project.

NASA facility construction projects have historically used a design-bid-build contract mechanism where the design and construction efforts are separated and different contractors are responsible for each stage of the project. The use of the design-build contract is a first for the Kennedy officials involved in ML-2. Although unusual for NASA, Kennedy officials said they chose the design-build contract because it gives the Agency the ability to increase communication and integration. According to those officials, design-build contracts have been successfully used by the Departments of Defense and Veterans Affairs, and are a common approach utilized by commercial industry. Under such a contract, the Agency expects to better facilitate builder involvement during design; utilize a single, integrated 3D model of ML-2 that improves communication of requirement changes; enable the contractor to suggest commercial best practices; better enable the monitoring of loads requirements; and require fewer parts to be designed and built by NASA for the contractor to install, known as government furnished equipment (GFE). While we are encouraged by this new approach, it is too early to determine if it will ultimately result in better cost and schedule outcomes for ML-2.

Builder Involvement during Design

Kennedy officials expect that a design-build contract will allow the builder to be more involved during the ML-2 design process to allow the construction team to better suggest alternative construction or design methods. For the ML-1 project, the design-bid-build approach did not enable the builder to be involved with the design process. In addition, the contractor responsible for subsystem design (Vencore) and the contractor responsible for construction (J.P. Donovan) were generally required to communicate in writing through NASA when contract modifications were necessary for the fixed-price construction project. According to ML-1 project personnel, this arrangement slowed communication between the contractors and reduced the ability of the builder to make suggestions to the designer on alternate materials or construction methods, reducing the opportunity for possible cost savings. Center officials said they anticipate the approach undertaken for ML-2 will allow designers and builders who work for the same company to better communicate throughout the construction process thereby facilitating a more efficient build of the structure.

Utilization of an Integrated 3D Model

Kennedy officials required the utilization of a single 3D project model in the ML-2 contract to better integrate components, manage requirement changes, and provide up-to-date designs for all stakeholders. During construction of ML-1, program officials cited instances when outdated design drawings were used and resulted in expensive rework to correct these errors. For example, J.P. Donovan personnel would attempt to install a cable or other item on ML-1 only to find the space already occupied by a part/structure not shown on the previous contractors' design drawings. This occurred because the design contractors were working from different designs and did not take care to ensure the plans were updated. In contrast, use of a single 3D model—a standard practice for commercial industry—is expected to avoid these situations during the design phase of ML-2.

Contractor-Suggested Best Practices

While reflecting on lessons learned from the ML-1 project and determining the path forward, the ML-2 Project Manager said they recognized that prescriptive specifications limited the ability of the contractors to use creative approaches to complete the project, including commercial best practices. With the new design-build approach for ML-2, Kennedy expects to implement a more flexible design process that will enable the contractor to propose more cost-effective approaches.

Monitoring Load Requirements

Kennedy expects the design-build approach to better incorporate ML-2's load requirements into the designs. Loads are created by the SLS during all phases of its service life, including assembly and transportation to the launch pad, environmental impacts such as wind, umbilicals, test firing, and liftoff. While constructing ML-1, load requirements were not properly characterized and communicated by NASA to the design contractors or integrated into the designs by the Agency. As a result, ML-1 costs increased by at least $10.3 million for installation of material to handle the loads. To address concerns with changes in load requirements, the Center will organize an ML-2 Loads Working Group to ensure all updated figures are available for NASA personnel as well as the Bechtel designers and engineers.

Less Government Furnished Equipment and Fabrication

As a key lesson learned from the ML-1 modification project, Kennedy officials required significantly less GFE than NASA provided for ML-1. The ML-1 project included approximately 800 items of GFE, which were difficult for the government to fabricate and provide to the construction contractor in accordance with the construction schedule. According to Kennedy officials, this resulted in equipment being provided to the contractor that was not ready for construction activities. The time required to complete or modify legacy support equipment eventually led to delays. For the ML-2 contract, Kennedy provided a list of 15 GFE items (such as EUS umbilicals and vehicle support posts) in the contract and the contractor will manage the logistics of delivering these items to the ML-2 construction site.

NASA Missing Opportunities for Improved Project Management and Oversight

ML-2 Schedule is Risky Due to Expected Requirements Changes and Limited Time for Testing

As noted, NASA encountered numerous requirements changes that resulted in significant cost increases and schedule delays while constructing ML-1, and the Agency expects to face similar challenges with ML-2. The design of the required capability and performance characteristics for ML-2 are driven by the specific needs of the SLS Block 1B vehicle and Orion spacecraft, as described in the Interface Control Document requirements, which are immature and have the possibility to change over time as NASA continues to develop those vehicles.[31] For example, during the ML-1 project, updated designs for the vehicle stabilizer system, which holds the vehicle in place on the launcher, were provided almost 15 months into the construction contract causing delays and additional costs. In addition, cost and schedule risks may increase given the potential for technical changes to SLS and Orion requirements either during or after the ML-2 design is complete. Although NASA expects fewer changes for ML-2 than during development of ML-1 due to the second launcher's design-build approach, ML-2 will likely experience changes such as those that may be required as the new EUS design matures. In addition, ongoing changes to the SLS Block 1B configuration could negatively affect cost and schedule. For example, the design for ML-2 may incorporate inaccurate assumptions when vehicle requirements are delayed that would require hardware to be reworked during the construction phase, increasing cost and delaying the schedule.

[31] An Interface Control Document specifies the exact mechanical, thermal, electrical, power, command, data, and other interfaces between elements of a system.

During MEV&V for ML-1, the project team conducted concurrent verification and validation testing while modifications were on-going. Concurrent verification and validation is not consistent with leading industry best practices because as construction is ongoing, the project office is forced to revalidate and reverify parts that have been modified after initial testing was done. The schedule for ML-2 allots 12 months for MEV&V, whereas this phase has taken at least 16 months for ML-1. Current estimates require ML-2 to be ready for MEV&V by November 2022 to meet Artemis IV flight hardware processing milestones. The testing schedule for ML-2 is based on current flight dates and any delays in development could impact the allotted time for testing, resulting in an overlap in testing and construction—one of the risks identified by the ML-1 project that the ML-2 project is attempting to avoid.

ML-2 Contract's Award Fees Could Limit Contractor Incentives to Control Cost and Schedule

Similar to the ML-1 outfitting design contract, NASA has used a cost-plus-award-fee contract for development of ML-2. According to Kennedy procurement officials, NASA is using this contract type because the SLS Block 1B requirements are still in development and changes to its design could flow down to the ML-2 requirements and impact the launcher's design. In addition, NASA procurement personnel said they wanted a performance award fee for ML-2 because it provides the Agency with greater flexibility in influencing a contractor's actions and allows the Agency to objectively measure the contractor's performance through the use of targeted milestones and an earned valued management system.[32]

As noted in the awarded contract, the Agency will encourage and reward the contractor for timely, safe, high-quality, and cost-effective performance. NASA will conduct the evaluation process semiannually and review factors such as technical and management performance (reviewing efficiency and effectiveness of design, technical and managerial integration, risk management, and construction), schedule performance (completion of milestones), cost control (measurement of the contractor's performance against the negotiated estimated cost of the contract), and small business utilization (success in fostering small business participation in the project).

However, a previous OIG audit found award-fee earnings inconsistent with contractor performance and showed that NASA's use of such awards may limit the Agency's ability to motivate contractors to improve performance and control costs. For example, in October 2018, we found that NASA inflated the ratings of The Boeing Company's (Boeing) performance for the SLS Program, leading to overly generous award fees on a contract that was billions of dollars over cost and several years behind schedule.[33] Specifically, in the six evaluation periods between fiscal years 2012 and 2018 in which NASA provided contractor ratings, Agency officials deemed Boeing's performance as "excellent" or "very good" despite the contractor's significant cost overruns and schedule delays. As a result, our report questioned nearly $64 million of the award fees provided to Boeing.

ML-1 has experienced a similar pattern with award-fees. For this audit, we reviewed NASA's evaluations of Vencore's performance for ML-1 during evaluation periods between fiscal years 2015 and 2018. Vencore's performance was rated as "excellent," "very good," or "good" despite the ML-1 project being significantly over budget and behind schedule. Specifically, we found design errors and significant

[32] Earned valued management is a tool for measuring and assessing project performance through the integration of technical scope with schedule and cost objectives during the execution of the project.

[33] NASA OIG, *NASA's Management of the Space Launch System Stages Contract* (IG-19-001, October 10, 2018).

contractor employee turnover increased the cost of the construction for ML-1 by nearly $48 million and caused significant schedule delays. In addition, when we reviewed Vencore's planned versus actual design costs for fiscal years 2015 through 2018, we found that the costs increased from a planned $34 million to more than $115 million.[34] Although not all of the increase to design cost is directly related to Vencore's performance, in our judgement, the significant amount of design errors contributed to the increased costs.

While we acknowledge the flexibility afforded by performance award fees, NASA's past use of this contracting vehicle for similar projects has been inconsistent with actual contractor performance and proven to be inadequate to control cost and schedule. One challenge to holding contractors more accountable is that because contractor milestones are developed during the project and not prior to awarding the contract, as technical challenges arise, NASA can reprioritize cost goals and milestones for the contract making it appear as though the contractor is performing well even when the contract is over budget and behind schedule. For example, Kennedy personnel responsible for rating Vencore's performance stated that even though design work was over budget and behind schedule they believed the contractor performed well due to the obstacles they had to overcome. As a result, Vencore received "excellent," "very good," or "good" ratings despite the ML-1 project being significantly over budget and behind schedule. Furthermore, NASA has a history of not enforcing award fee rating criteria and providing contractors with high award ratings and related award fees they have not earned.

NASA's Approach to Managing the ML-2 Project Lacks Key Project Management Requirements That Would Provide Additional Oversight and Transparency

ML-2 faces numerous cost, schedule, and technical risks as it moves into development. During our examination of lessons learned for the development of ML-1, we found several instances where separate and more detailed information on life-cycle and milestone reviews, commitments to budgets separate from the EGS Program, and identification and management of risks could have brought more transparency and therefore oversight to the project to improve results. Although too late to incorporate these changes into management of the ML-1 project, there is still time to adjust the management approach for the ML-2 project to provide greater levels of oversight and transparency. Without greater insight into the ML-2 project, NASA managers and external decision makers, such as the Office of Management and Budget and Congress, will have limited information to make informed decisions on the project.

Life-Cycle and Milestone Reviews

Life-cycle and milestone reviews provide periodic assessments of technical and programmatic status and health at key points in a project's life-cycle. However, because the ML-1 element was rolled into the larger EGS Program, these reviews were not completed specifically for the ML-1 project, and any reviews conducted of the EGS Program provided limited visibility into the ML-1 project. For example, during formulation and the beginning years of the EGS Program, early life-cycle and milestone reviews for the Program, such as the Preliminary Design Review, occurred after the ML-1 project had already

[34] The Vencore design activities were migrated to a new contractor in December 2018. The planned amount should have finished the project; however significant design work was necessary after the 2018 migration. The $115 million only includes the actual costs for Vencore's work and does not include any remaining work.

advanced to its next phase of development.[35] Specifically, when the EGS Program performed the Preliminary Design Review in December 2013, the ML-1 structural construction contract had already been awarded 7 months earlier making this review less meaningful for the ML-1 project.

For other reviews, the ML-1 project was often not required to fully explain risks or actions taken to mitigate risks, which limited managers' ability to make recommendations. For example, when EGS performed the System Requirements Review in July 2012, the ML-1 project had a significant number of immature requirements relating mostly to umbilicals and load requirements.[36] However, documentation from that review did not include any information from the ML-1 project identifying these immature requirements or discussing how the additional risk of moving forward would be mitigated. In our judgement, the life-cycle reviews conducted by the EGS Program, especially early in the ML-1 project's development cycle, limited NASA managers and policymakers/stakeholders ability to adequately assess the project's status and conduct appropriate oversight. As of January 2020, ML-2 project officials were in the process of determining how life-cycle reviews will be conducted for the ML-2 project. Without milestone reviews that are more specific to the ML-2 project and communicated with NASA's senior management, project oversight is diminished, hindering the Agency's ability to make timely adjustments to a project that has significant risk of cost and schedule increases.

Baseline and Rebaseline Requirements

Because ML-1 was considered a sub-project under the EGS Program, it was not required to conduct an Agency Baseline Commitment (ABC) or perform rebaselining activities separate from the EGS Program as a whole.[37] With total costs for modifying ML-1 more than doubling from the initial March 2014 cost estimate (from $174 million to $482 million), a rebaseline would have been required and may have provided opportunity for NASA and Congress to review the project and assess the best path forward prior to appropriating additional funds. The EGS Program established its ABC in 2014, 1 year after work began on modifying ML-1, therefore missing an opportunity to establish more realistic cost estimates and more aggressive cost controls. Even though the ML-2 project exceeds the cost threshold to establish an ABC under NASA guidance, EGS has not established one for the ML-2 project. As of January 2020, EGS officials are determining if an ABC should be required specifically for the ML-2 project. Without an ABC, Agency officials would not be required to examine the reasons for significant funding and schedule increases or reductions in ML-2 technical capabilities, which limits NASA's ability to make adjustments to the project.

Risk Management

The ML-1 project's risk management and monitoring could have been more complete and transparent. For example, in September 2016, the construction contractor (J.P. Donovan) discovered that the ML-1 tower had shifted or developed a slight lean towards its exhaust hole. Kennedy created an inquiry team of engineers independent of the design and construction process to examine the issue and identify

[35] A Preliminary Design Review demonstrates that the preliminary design meets all system requirements with acceptable risk and within the cost and schedule constraints and establishes the basis for proceeding with detailed design.

[36] A Systems Requirements Review is used to ensure that requirements are properly formulated and correlated with the Agency and mission directorate strategic objectives. The review also examines the functional and performance requirements defined for the system and preliminary program plan and ensures that the requirements and the selected concept will satisfy the mission.

[37] An ABC is a set of requirements, including cost, schedule, and technical content, that form the foundation for NASA's commitment to Congress that a project can be developed for a set amount of money and time.

events or conditions that could have contributed to the root cause. The inquiry team determined through numerous post fabrication surveys and digital scans that the tower had in fact shifted between 0.25 inches and 0.36 inches towards the exhaust hole. The team also concluded that the most likely cause were shims—that is, strips of material that were utilized to align parts and make them fit—that had not been removed during tower tier installation, allowing the lower portion of the tower to shift or flex during an October 2010 move at Kennedy. The inquiry team developed a list of recommendations that mostly centered on how future surveys and scans would be taken to continuously monitor the lean and mitigate future impacts.

While these actions reflect activities that are traditionally completed as part of risk management and risk monitoring, the ML-1 Project Manager told us the lean issue was never considered to be a formal risk. While the ML-1 project office tracked risks internally in monthly briefings with the ML-1 Project Manager, these risks were often not included in the official risk management system, resulting in less transparency to NASA management outside the project and external stakeholders, reducing the likelihood that residual risks would be adequately monitored or communicated.

CONCLUSION

When complete, NASA expects ML-1 and ML-2 to serve as the ground structures that will assemble, process, transport, and launch NASA's integrated SLS/Orion system to the Moon and eventually Mars. The ML-1 project's development has been subject to changing priorities and integration challenges, with modifications more than doubling its initial projected price and the schedule for completing slipping more than 3 years. Moreover, when the costs associated with development of the Ares I mobile launcher are included, the projected total cost for ML-1 of $927 million represents a substantial investment for the currently projected three or four missions that will launch from the structure—a cost per mission of between $232 million and $309 million, depending on the number of missions. As we have reported, other programs that support the Artemis missions such as SLS and Orion are also significantly over budget and behind schedule.[38]

NASA experienced significant cost and schedule growth on the ML-1 project due to the Agency's acquisition approach and immature SLS requirements that resulted in design errors and integration challenges. We found that NASA's acquisition strategy for ML-1 did not provide for effective coordination among the various design activities and could have benefited from additional competition when identifying a design contractor that specializes in large complex construction projects. In addition, immature or undefined SLS and Orion requirements caused numerous design changes for ML-1 that contributed to the project's cost increases and schedule delays.

As NASA begins to develop ML-2, the Agency is anticipating the use of a single contract to both design and build the structure will remedy the majority of the communication and integration issues that occurred during the ML-1 project and led to substantial cost and schedule overages. While we are encouraged by this approach, it is too early to determine if this approach will result in better cost and schedule outcomes for ML-2. ML-2 is a high-risk project that faces numerous cost, schedule, and technical risks. As such, we are concerned that the project's schedule presents significant risk due to expected requirements changes and a limited amount of time allotted for testing. In addition, NASA's continued use of a cost-plus-award-fee contract could lead to overly generous award fees that do not match acquisition outcomes. Finally, continuing to manage the ML-2 project as an element of the larger EGS Program increases the risk that senior NASA managers and external decision makers may lack the information necessary to make more informed decisions on the project's life-cycle and milestone reviews, commitments to budgets separate from the EGS Program, and identification and management of risks.

[38] IG-19-001 and NASA OIG, *NASA's Management of the Orion Multi-Purpose Crew Vehicle Program* (IG-16-029, September 6, 2016).

RECOMMENDATIONS, MANAGEMENT'S RESPONSE, AND OUR EVALUATION

We made the following recommendations to NASA's Associate Administrator for Human Exploration and Operations Mission Directorate to improve potential outcomes for the ML-2 development:

1. Identify immature vehicle load and interface requirements for the ML-2 project and coordinate with appropriate offices to mitigate cost and schedule risks.
2. Develop a process to ensure contractor performance ratings and related award fees for the ML-2 contract are consistent with established criteria and project outcomes.
3. Ensure life-cycle and milestone reviews incorporate programmatic and technical risks and are conducted with the Associate Administrator for Human Exploration and Operations Mission Directorate and other senior Agency officials.
4. Require the ML-2 project to develop an ABC separate from the EGS Program.

We provided a draft of this report to NASA management who concurred with the recommendations and described planned actions to address them. We consider the proposed actions responsive and will close the recommendations upon completion and verification of the proposed actions.

Management's comments are reproduced in Appendix C. Technical comments provided by management have also been incorporated, as appropriate.

Major contributors to this report include Ridge Bowman, Space Operations Director; Mike Brant, Project Manager; Rachel Pierre; Alyssa Sieffert; Dimitra Tsamis; Troy Zigler; and Sarah McGrath.

If you have questions about this report or wish to comment on the quality or usefulness of this report, contact Laurence Hawkins, Audit Operations and Quality Assurance Director, at 202-358-1543 or laurence.b.hawkins@nasa.gov.

Paul K. Martin
Inspector General

Appendix A: Scope and Methodology

We performed this audit from October 2018 through January 2020 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. The scope of this audit included cost, schedule, and performance of the ML-1 project and best practices and lessons-learned for the ML-2 project.

To obtain an understanding of the concerns and delays with building ML-1 and expectations for building ML-2, we interviewed EGS Program personnel located at Kennedy. We also interviewed RS&H, Jacobs, and J.P. Donavan contractor personnel. We reviewed the intended objectives established by the EGS Program for ML-2 through the request for proposal and procurement documentation. Finally, we reviewed federal, NASA, and EGS criteria, policies and procedures and supporting documentation, prior audit reports, and other documents related to the construction of ML-1 and ML-2. The documents we reviewed included, but were not limited to, the following:

- *NASA Systems Engineering Handbook* (December 2007)
- Aerospace Safety Advisory Panel, *Annual Report* (January 2018)
- NASA Procedural Requirement 7120.5E, *NASA Space Flight Program and Project Management Requirements* (August 2012)

Use of Computer-Processed Data

Our audit conclusions did not rely on computer-processed data. However, our audit used limited computer-processed data that we assessed as reliable. Primarily, we used budget and financial information provided by Kennedy's Office of the Chief Financial Officer. Additionally, we discussed with the ML-2 project office how budget estimates were developed.

Review of Internal Controls

We performed an assessment of internal controls associated with NASA's management of award fees and project management. The control weaknesses we identified are discussed in this report. Our recommendations, if implemented, should correct the identified control weaknesses.

Prior Coverage

During the last 5 years, the NASA OIG and the Government Accountability Office (GAO) have issued 10 reports of significant relevance to the subject of this report. Unrestricted reports can be accessed at https://oig.nasa.gov/audits/auditReports.html and http://www.gao.gov respectively.

NASA Office of Inspector General

NASA's Management of Space Launch System Program Costs and Contracts (IG-20-012, March 10, 2020)

NASA's Management of the Space Launch System Stages Contract (IG-19-001, October 10, 2018)

NASA's Management of the Orion Multi-Purpose Crew Vehicle Program (IG-16-029, September 6, 2016)

Audit of NASA's Engineering Services Contract at Kennedy Space Center (IG-16-017, May 5, 2016)

NASA's Launch Support and Infrastructure Modernization: Assessment of the Ground Systems Needed to Launch SLS and Orion (IG-15-012, March 18, 2015)

Government Accountability Office

NASA Assessments of Major Projects (GAO-17-303SP, May 16, 2017)

Delay Likely for First Exploration Mission (GAO-17-414, April 27, 2017)

Opportunity Nears to Reassess Launch Vehicle and Ground Systems Cost and Schedule (GAO-16-612, July 27, 2016)

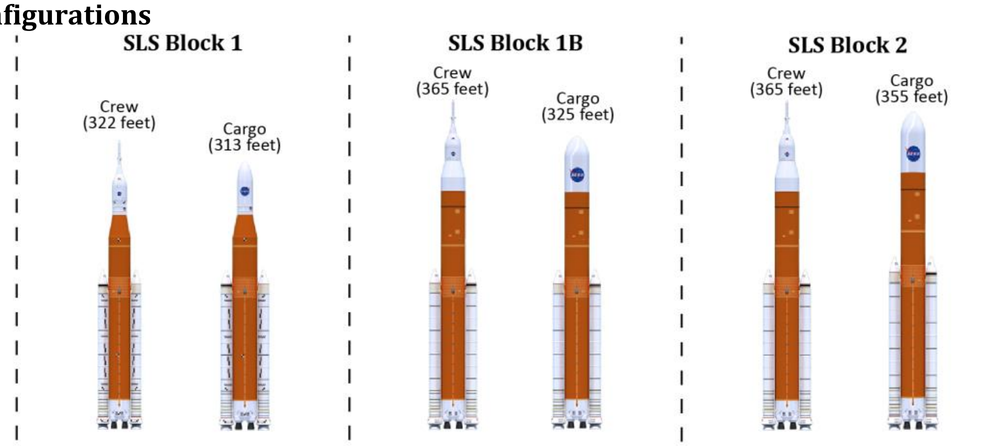
NASA Assessments of Major Projects (GAO-16-309SP, March 30, 2016)

Human Space Exploration Programs Face Challenges (GAO-15-248T, December 10, 2014)

Appendix B: SLS Configurations and Artemis Launch Schedule

As shown in Figure 9, NASA plans to incrementally increase SLS performance capabilities through a series of upgrades to its Solid Rocket Boosters and Upper Stage. The initial SLS Block 1 configuration, intended for use on Artemis I, Artemis II, Artemis III, and potentially SM-1, will be able to lift 70 metric tons to low Earth orbit. Future launches beginning in 2025 are expected to use the SLS Block 1B configuration, which includes the EUS, to increase upmass capability to 105 metric tons. Finally, the SLS Block 2 configuration will replace the Solid Rocket Boosters from Blocks 1 and 1B with advanced Boosters that will provide the capability to lift 130 metric tons to low Earth orbit and 37 metric tons to Mars. Missions that utilize SLS Block 1, will launch from ML-1, while missions that utilize SLS Block 1B or SLS Block 2 will launch from ML-2.

Figure 9: SLS Configurations



	SLS Block 1	SLS Block 1B	SLS Block 2
Launch readiness date	2020	2025	no earlier than 2030
Missions	Artemis I, Artemis II, Artemis III, and SM-1	Artemis IV through Artemis IX	TBD
Vehicles needed	4	6	to be determined
Upgrades	n/a	Exploration Upper Stage	Advanced Boosters
Mobile launcher	ML-1	ML-2	ML-2

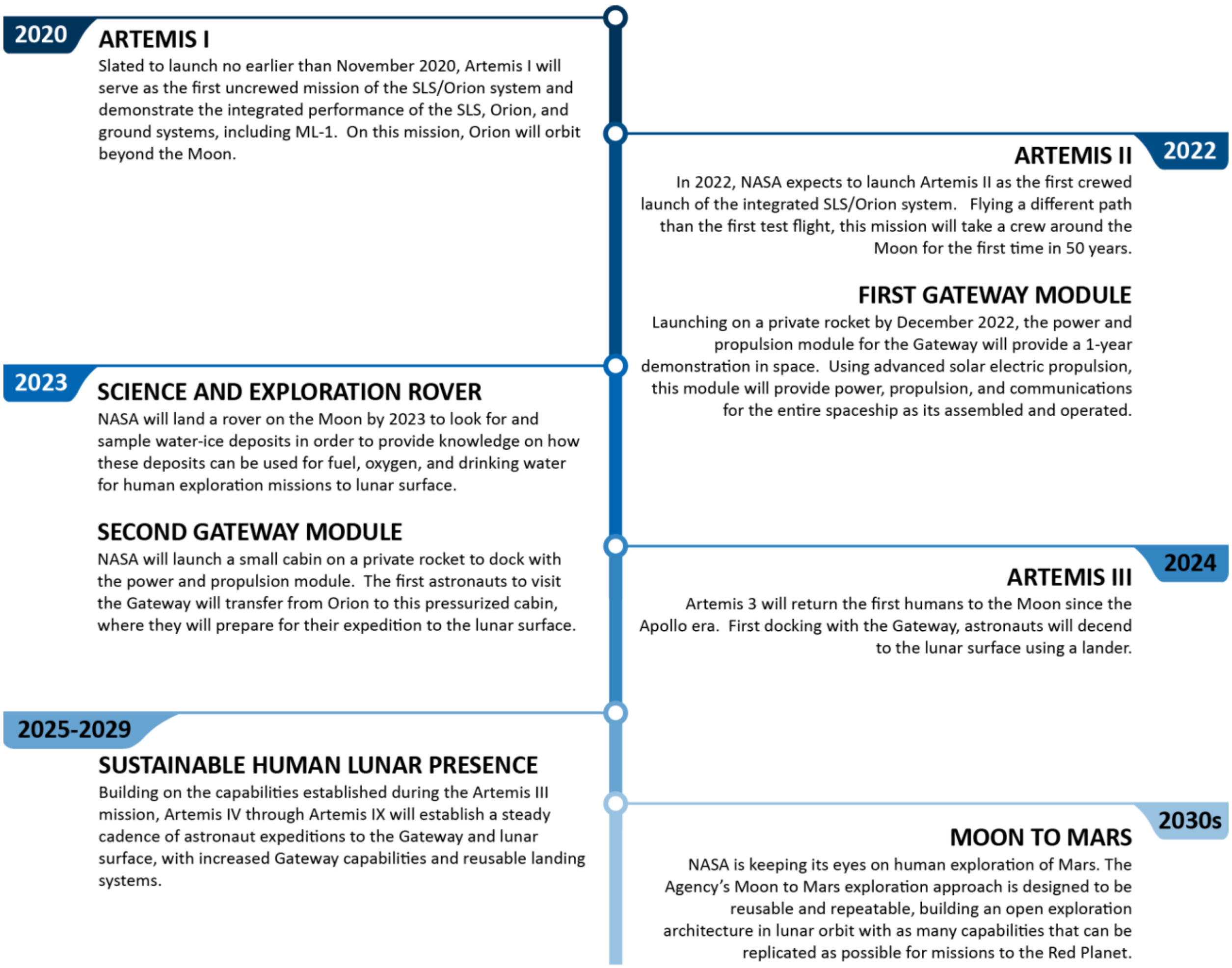
Source: NASA OIG analysis of Agency Information.

As shown in Figure 10, through a series of missions beginning in 2020 and extending into the 2030s, NASA plans to establish a sustained presence on and around the Moon and lay the foundation for the future exploration of Mars. No earlier than November 2020, NASA plans to launch Artemis I as the first uncrewed mission of the integrated SLS/Orion system.[39] Artemis I will demonstrate the integrated performance of the SLS, Orion, and ground systems such as ML-1. By the fall of 2022, NASA plans to launch Artemis II as the first crewed launch of the integrated system sending astronauts on a lunar fly-by test. Following those missions, in 2022 and 2023 NASA expects to launch a series of missions to begin assembly of the Lunar Gateway, a small spaceship in orbit around the Moon that would enable astronauts

[39] As of January 2020, NASA anticipates the Artemis I launch date will slip to spring 2021.

access to the entire surface of the Moon, as well as landing a rover on the Moon to search for and sample water-ice deposits. By 2024, NASA plans to launch Artemis III with the hope of returning humans to the surface of the Moon for the first time since the Apollo era. Artemis III will be followed by a series of planned additional missions to the Lunar Gateway and Lunar surface in the 2026 to 2029 timeframe.

Figure 10: Artemis Launch Schedule



Source: NASA OIG analysis of Agency information.

APPENDIX C: MANAGEMENT'S COMMENTS

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

MAR - 5 2020

Reply to Attn of: Human Exploration and Operations Mission Directorate

TO: Assistant Inspector General for Audits

FROM: Associate Administrator for Human Exploration and Operations Mission Directorate

SUBJECT: Agency Response to OIG Draft Report, "Audit of NASA's Development of Its Mobile Launchers" (A-18-008-01)

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to review and comment on the Office of Inspector General (OIG) draft report entitled, "Audit of NASA's Development of Its Mobile Launchers" (A-18-008-01), dated February 3, 2020.

In the draft report, the OIG fairly describes the challenges NASA faced when the Constellation Program was cancelled, and the Agency was provided Congressional direction to use, to the extent practicable, existing infrastructure in developing and operating the Space Launch System, which included a mobile launcher. With this direction, NASA initiated significant modification of the Ares 1 mobile launcher to transform it into Mobile Launcher 1 (ML-1) – a mobile launcher that would be capable of launching the Space Launch System (SLS) launch vehicle, which is a much larger, much heavier launch vehicle with a rocket configuration that is significantly different from the Ares 1 rocket that it was originally built to launch. NASA is using lessons learned from ML-1 to improve cost and schedule performance on ML-2.

In the draft report, the OIG makes four recommendations addressed to the Associate Administrator for Human Exploration and Operations, intended to improve potential outcomes for ML-2 development.

Specifically, the OIG recommends the following:

Recommendation 1: Identify immature vehicle load and interface requirements for the ML-2 project and coordinate with appropriate offices to mitigate cost and schedule risks.

Management's Response: NASA concurs. ML-2 is being designed and built under a single contract which significantly improves communication and integration. This technical integration between programs will continue throughout the ML-2 design process. The offices-of-primary-responsibility and personnel counterparts have been well-established and frequent formal and informal cross-program communication is occurring. The ML-2 System Requirements Review was just completed on January 31, 2020.

Estimated Completion Date: Complete

Recommendation 2: Develop a process to ensure that contractor performance ratings and related award fees for the ML-2 contract are consistent with established criteria and project outcomes.

Management's Response: NASA concurs and believes that its implementation of existing policies and lessons learned on the ML-2 contract, including the frequency of award fee determination, will ensure ratings are consistent with project outcomes. In the ML-2 contract, the award fee is determined every six months. In addition, the Exploration Ground Systems program has emphasized to its technical monitors that ratings given must be consistent with contractor performance and existing policies.

Estimated Completion Date: Complete

Recommendation 3: Ensure life-cycle and milestone reviews incorporate programmatic and technical risks and are conducted with the Associate Administrator for Human Exploration and Operations Directorate and other senior Agency officials.

Management's Response: NASA concurs. Life-cycle and milestone reviews, that incorporate programmatic and technical risks, will be conducted with the Associate Administrator for Human Exploration and Operations and other senior Agency officials as established in NASA Procedural Requirements (NPR) 7120.5, "NASA Space Flight Program and Project Management Requirements."

Estimated Completion Date: April 30, 2020

Recommendation 4: Require the ML-2 project to develop an Agency Baseline Commitment (ABC) separate from the EGS Program.

Management's Response: NASA concurs. NASA will establish an ABC for ML-2 after the SLS Block 1B and Exploration Upper Stage Critical Design Reviews.

Estimated Completion Date: May 31, 2021.

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

Once again, thank you for the opportunity to review and comment on the subject draft report. If you have any questions or require additional information regarding this response, please contact Lynne Loewy on (202) 358-0549..

Douglas Loverro

APPENDIX C: REPORT DISTRIBUTION

National Aeronautics and Space Administration

Administrator
Deputy Administrator
Associate Administrator
Chief of Staff
Associate Administrator for Human Exploration and Operations Mission Directorate
Director, Kennedy Space Center

Non-NASA Organizations and Individuals

Office of Management and Budget
Deputy Associate Director, Energy and Space Programs Division

Government Accountability Office
Director, Contracting and National Security Acquisitions

Congressional Committees and Subcommittees, Chairman and Ranking Member

Senate Committee on Appropriations
Subcommittee on Commerce, Justice, Science, and Related Agencies

Senate Committee on Commerce, Science, and Transportation
Subcommittee on Aviation and Space

Senate Committee on Homeland Security and Governmental Affairs

House Committee on Appropriations
Subcommittee on Commerce, Justice, Science, and Related Agencies

House Committee on Oversight and Reform
Subcommittee on Government Operations

House Committee on Science, Space, and Technology
Subcommittee on Investigations and Oversight
Subcommittee on Space and Aeronautics

(Assignment No. A-18-008-01)