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NASA's Development of Next-Generation Spacesuits

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NASA Office of Inspector General
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Results in Brief

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August 10, 2021 IG-21-025 (A-20-015-00)

Why We Performed This Audit

The development of new spacesuits is a critical component of achieving NASA's goals of returning humans to the Moon, continuing safe operations on the International Space Station (ISS), and exploring Mars and other deep space locations. For extravehicular activities such as spacewalks or exploring the lunar surface, astronauts require Extravehicular Mobility Units (EMU), which includes the spacesuit itself and the hardware that physically connects the EMU to the ISS and other space systems. Currently, astronauts use EMUs designed 45 years ago for the Space Shuttle Program and rely on these refurbished and partially redesigned spacesuits for extravehicular activities on the ISS.

For the past 14 years, NASA has been developing next-generation spacesuit technology, which 5 years ago led to the creation of the project known as the Exploration Extravehicular Mobility Units (xEMU) that will be used to support astronaut involvement in multiple programs. Specifically, the xEMU will be used on the ISS and Artemis missions involving both the Gateway and Human Landing System (HLS). We reported in 2017 that despite spending nearly $200 million on extravehicular spacesuit development over the previous 9-year period, the Agency remained years away from having a flight-ready spacesuit to use on exploration missions. Since our 2017 report, NASA has spent an additional $220 million—for a total of $420 million—on spacesuit development.

This audit examined NASA's development of next-generation spacesuits for ISS and Artemis missions. Specifically, we examined the extent to which NASA is addressing challenges related to cost, schedule, and performance of the next-generation spacesuit system. To accomplish our objective, we performed work at Johnson Space Center and Marshall Space Flight Center. We reviewed and analyzed NASA's financial accounting system; planning, programming, budgeting, and execution information; and relevant laws and regulations. We also interviewed NASA project officials and reviewed stakeholder requirements documents and key NASA policies and procedures governing risk management.

What We Found

NASA's current schedule is to produce the first two flight-ready xEMUs by November 2024, but the Agency faces significant challenges in meeting this goal. This schedule includes approximately a 20-month delay in delivery for the planned design, verification, and testing suit, two qualification suits, an ISS Demo suit, and two lunar flight suits. These delays—attributable to funding shortfalls, COVID-19 impacts, and technical challenges—have left no schedule margin for delivery of the two flight-ready xEMUs. Given the integration requirements, the suits would not be ready for flight until April 2025 at the earliest. Moreover, by the time two flight-ready xEMUs are available, NASA will have spent over a billion dollars on the development and assembly of its next-generation spacesuits.

Given these anticipated delays in spacesuit development, a lunar landing in late 2024 as NASA currently plans is not feasible. That said, NASA's inability to complete development of xEMUs for a 2024 Moon landing is by no means the only factor impacting the viability of the Agency's current return-to-the-Moon timetable. For example, our previous audit work identified significant delays in other major programs essential to a lunar landing, including the Space Launch System rocket and Orion capsule. Moreover, delays related to lunar lander development and the recently decided lander contract award bid protests will also preclude a 2024 landing.

As spacesuit development continues, evolving and competing requirements from key program stakeholders such as the HLS, ISS, and Gateway increases the risk of future cost, schedule, and performance issues. Additionally, prior to their use on ISS and Artemis missions, astronauts will require suits for training. However, training needs across the stakeholders—particularly the ISS and HLS programs—do not align with projections of when suit hardware will be available. Specifically, the EVA Office is concerned there will not be sufficient quantities of training hardware available for early training events to support the currently planned 2024 Artemis III mission.

As NASA continues to develop and mature its next-generation spacesuit capabilities, the Agency must decide on its approach to procuring additional suits for both ISS and Artemis missions. In October 2019, NASA issued a Request for Information (RFI) to determine industry capabilities to fulfill future spacesuit needs. At that time, NASA intended to initiate a hybrid contract consisting of a single prime contractor for integration and multiple awards for development and sustainment known as the Exploration Extravehicular Activity Production and Services (xEVAPS) contract. However, after 18 months NASA canceled the xEVAPS RFI and issued a new RFI in April 2021 for the Exploration Extravehicular Activity Services (xEVAS), significantly altering its approach for future suit acquisition by purchasing services instead of equipment. As previously discussed, to date NASA has spent more than $420 million on spacesuit design and development, but the new xEVAS RFI gives industry the choice to either leverage NASA's designs or propose their own. Therefore, the extent to which NASA's investments will be utilized is unclear. Additionally, the xEVAS RFI does not stipulate that the suit be compatible with both the ISS and Artemis programs, a distinction that could result in industry developing (and NASA purchasing) two different spacesuits—one for use in low Earth orbit on the ISS and another for use on the lunar surface during Artemis missions. Given the Station's limited expected lifespan, developing a suit solely for the ISS may not prove cost effective.

WHAT WE RECOMMENDED

To ensure the successful development of the xEMU, we made four recommendations to the Associate Administrator for the Human Exploration and Operations Mission Directorate, including (1) adjusting the schedule as appropriate to reduce development risks; (2) developing an integrated master schedule to incorporate and align the hardware deliveries and training needs of the dependent Programs—Gateway, ISS, and HLS—and the Flight Operations Directorate; (3) ensuring technical requirements for the next-generation suits are solidified before selecting the acquisition strategy to procure suits for the ISS and Artemis programs; and (4) developing an acquisition strategy for the next-generation spacesuits that meets the needs of both the ISS and Artemis programs.

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

TABLE OF CONTENTS

Acronyms

DVT	Design Verification and Testing
EMU	Extravehicular Mobility Units
EVA	Extravehicular Activity
FOD	Flight Operations Directorate
FY	fiscal year
HLS	Human Landing System
ISS	International Space Station
OIG	Office of Inspector General
PGS	Pressure Garment System
PLSS	Primary Life-Support System
RFI	Request for Information
SERFE	Spacesuit Evaporation Rejection Flight Experiment
VISE	Vehicle Interface to Suit Equipment
xEMU	Exploration Extravehicular Mobility Units
xEVA	Exploration Extravehicular Activity
xEVAPS	Exploration Extravehicular Activity Production and Services
xEVAS	Exploration Extravehicular Activity Services
xINFO	Exploration Informatics Subsystem
xPGS	Exploration Pressure Garment Subsystem
xPLSS	Exploration Portable Life-Support Subsystem

INTRODUCTION

The development of new spacesuits is a critical component of achieving NASA's goals of returning humans to the Moon, continuing safe operations on the International Space Station (ISS or Station), and exploring Mars and other deep space locations. For extravehicular activities such as spacewalks, astronauts require Extravehicular Mobility Units (EMU), which includes the spacesuit itself and the hardware that physically connects the EMU to the ISS and other space systems. Currently, astronauts use EMUs that were designed 45 years ago for the Space Shuttle Program and rely on these refurbished and partially redesigned spacesuits for extravehicular activities on the ISS.

NASA has been developing next-generation spacesuit technology for the past 14 years and 5 years ago created the project known as the Exploration Extravehicular Mobility Units (xEMU). As part of the Exploration Extravehicular Activity (xEVA) system, the xEMU will support astronauts on the ISS and during future Artemis missions both on the Gateway and during a lunar landing using the Human Landing System (HLS).[1] In 2017, we reported that despite spending nearly $200 million on extravehicular spacesuit development over a 9-year period, the Agency remained years away from having a flight-ready spacesuit to use on exploration missions.[2] Since our 2017 report on the Agency's spacesuit development efforts, NASA has spent an additional $220 million—for a total of $420 million—and a flight-ready xEMU remains about 4 years away.

This audit examines NASA's development of next-generation spacesuits for ISS and Artemis missions. Specifically, we examined the extent to which NASA is addressing challenges related to cost, schedule, and performance of the xEVA system development and production.[3] See Appendix A for details of the audit's scope and methodology.

Background

Astronauts must wear spacesuits—essentially personal spacecraft—to keep them safe in the harsh environment of space when outside the ISS, lunar lander, or any other capsule or spacecraft. There are two types of spacesuits: intravehicular suits, which are worn inside a spacecraft, and extravehicular suits, which are worn for exploring outside of a spacecraft. NASA has utilized spacesuits since 1959 for both types of activities. The EMU design was initiated in 1974 by Hamilton Standard and ILC Dover for the Space Shuttle Program. This "baseline" EMU went into flight service in 1981, and in 1990, NASA and ILC Dover developed the "enhanced" version that is currently in use for spacewalks on the ISS.[4] The goal

[1] The Gateway will provide a staging location for lunar and deep space missions and, according to NASA, is essential to support sustained Artemis operations. The HLS will ferry astronauts from either the Orion Multi-Purpose Crew Vehicle (Orion) capsule in lunar orbit or Gateway to the Moon's surface.

[2] NASA OIG, *NASA's Management and Development of Spacesuits* (IG-17-018, April 26, 2017).

[3] The xEVA system includes the suit itself (the xEMU) and the supporting projects and products necessary to safely use the suit in flight and while testing and training on the ground.

[4] While the first iteration of the EMU, known as the "baseline" EMU, was designed for contingency scenarios for the Space Shuttle Program, the "enhanced" EMU was designed to accommodate an increase in the number of extravehicular activities required to assemble, repair, and maintain the ISS.

of NASA's ongoing spacesuit development efforts is to build an xEMU to replace the ISS suits and to enable human exploration on the Moon and eventually in deep space environments, including missions to Mars.

Next-Generation Extravehicular Spacesuit Efforts

Since 2007, NASA has embarked on three separate extravehicular spacesuit development efforts: (1) the Constellation Space Suit System; (2) the Advanced Space Suit Project; and (3) the xEMU, which has been funded by two separate Agency programs (see Figure 1). Between 2007 and 2016, NASA developed spacesuit technologies in parallel through the Constellation Space Suit System and the Advanced Space Suit Project. When the Constellation Program was canceled in October 2010, NASA officials opted to continue portions of the Constellation Space Suit System contract through January 2016 to develop spacesuit technologies.[5] However, after cancelation of the Constellation Program, the Advanced Space Suit Project became NASA's primary spacesuit technology development effort and resulted in the Z-1 and Z-2 pressure garment prototypes and a newly developed advanced portable life support system for testing.[6] In 2016, NASA consolidated the efforts from both projects under the Extravehicular Activity (EVA) Office to continue in-house development of the xEMU.

[5] The Constellation Space Suit System contract was funded by the Orion Program from fiscal year 2009 through fiscal year 2012. In fiscal year 2012, funding for the contract was transitioned to the ISS Program through fiscal year 2015.

[6] The Z-1 pressure garment prototype consisted of separate efforts by Oceaneering International, Inc. and ILC Dover that were later integrated by NASA. The suit featured rear entry and a soft upper torso with increased mobility through modified shoulder and hip joints and the ability to operate at different pressures. The Z-2 prototype featured numerous upgrades from the Z-1, including improved upper and lower mobility to allow astronauts to walk over rough terrain, kneel and pick up objects, and rise from a supine position, all activities needed for future exploration missions. The Z-2 also included weight reduction technologies and a composite upper torso.

Figure 1: NASA's Spacesuit Development Efforts, Fiscal Years 2008 through 2021

			
Program/Project	**Constellation Program EVA Project (Constellation Space Suit System)**	**Advanced Exploration Systems Division (Advanced Space Suit Project)**	**EVA Office (xEMU)**
Area of Emphasis	Launch, Entry, and Abort Suit; and EVA, Pressure Garment Subsystem (PGS), and Primary Life-Support System (PLSS) prototypes	EVA PGS and PLSS prototypes	xEMU, the dedicated EVA suit for use during lunar flight dynamic phases, microgravity EVAs, and lunar surface excursions
Status	Contract ended	Transferred to ISS	In development
Prime Contractor	Oceaneering International	NASA (in-house)	NASA (in-house)
Dates of Development	2009 - January 2016	2007-2016	2016 - present[a]
Cost (in millions)	$135.7	$51.6	$232.8[b]

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

[a] From fiscal year 2016 to December 2020, the ISS Program provided funding to the EVA Office. Since October 2019, the Gateway Program has provided funding to the EVA Office.

[b] As of December 2020, the xEMU development cost was $231.5 million under the ISS Program and $1.3 million under the Gateway Program.

As of July 2021, none of these efforts have resulted in a flight-ready spacesuit. Development of the xEMU came in response to NASA's realization that the 45-year-old suits used on the ISS needed to be replaced, coupled with a congressional mandate under the NASA Transition Authorization Act of 2017 to submit a plan for an advanced suit to meet the needs of deep space exploration.[7] In response, NASA's EVA Office started developing the xEMU to replace the aging EMU for use on the ISS and to fulfill the needs of the Artemis missions. Specifically, NASA needs two fully functioning xEMUs to enable astronauts to explore the Moon's surface during the Artemis III mission, currently planned for late 2024.[8]

Spacesuit Management and Organizational Structure

The EVA Office at Johnson Space Center manages the development of the xEMU and NASA's extravehicular activities through its xEVA Project. In July 2019, with the decision to leverage the xEMU for missions to the lunar surface, the xEVA Project was moved under the Gateway Program. Previously, NASA was developing the xEMU spacesuit without a specific program in mind; therefore, the xEVA Project operated independently from any particular program office.[9] Although programmatic authority for the office now falls under the Gateway Program, both the HLS and ISS programs remain major stakeholders in the xEVA Project.[10]

The Gateway and HLS programs are part of the Advanced Exploration Systems Division, which along with the ISS Program falls under the Human Exploration and Operations Mission Directorate.[11] See Figure 2 for the management and organization structure for the EVA Office.

[7] National Aeronautics and Space Administration Transition Authorization Act of 2017, Pub. L. No. 115-10 (2017). The Act directed the Agency to submit to Congress a plan for "achieving an advanced space suit capability that aligns with the crew needs for exploration enabled by the Space Launch System and Orion, including an evaluation of the merit of delivering the planned suit system for use on the ISS."

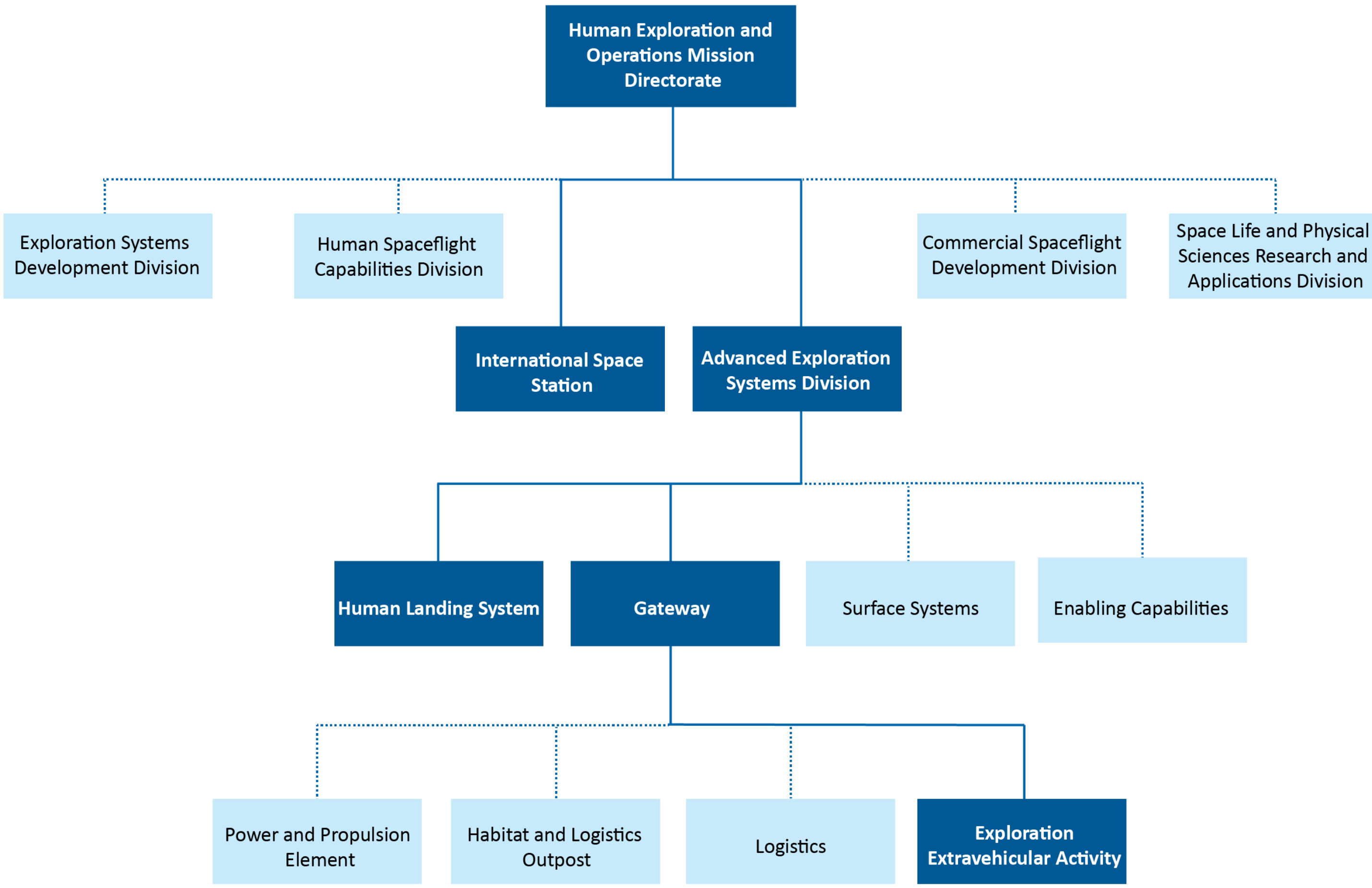
[8] Artemis I is an uncrewed mission that will serve as the first test of the combined Space Launch System/Orion system, while Artemis II is planned as a crewed mission that will orbit the Moon.

[9] IG-17-018.

[10] NASA Procedural Requirement 7120.5E, *NASA's Space Flight Program and Project Management Requirements* (August 14, 2012). According to *Program and Project Management Roles and Responsibilities*, programmatic authority consists of NASA's mission directorates and their respective programs and projects. Programmatic authority allows mission directorates to, among other duties, establish directorate policies for their programs, projects, and supporting elements; support the Agency's strategic acquisition process; initiate new programs and projects; establish program and project budgets; oversee program and project performance; and approve launch readiness.

[11] In addition to Human Exploration and Operations Mission Directorate, NASA's other mission directorates include Aeronautics Research, Science, and Space Technology.

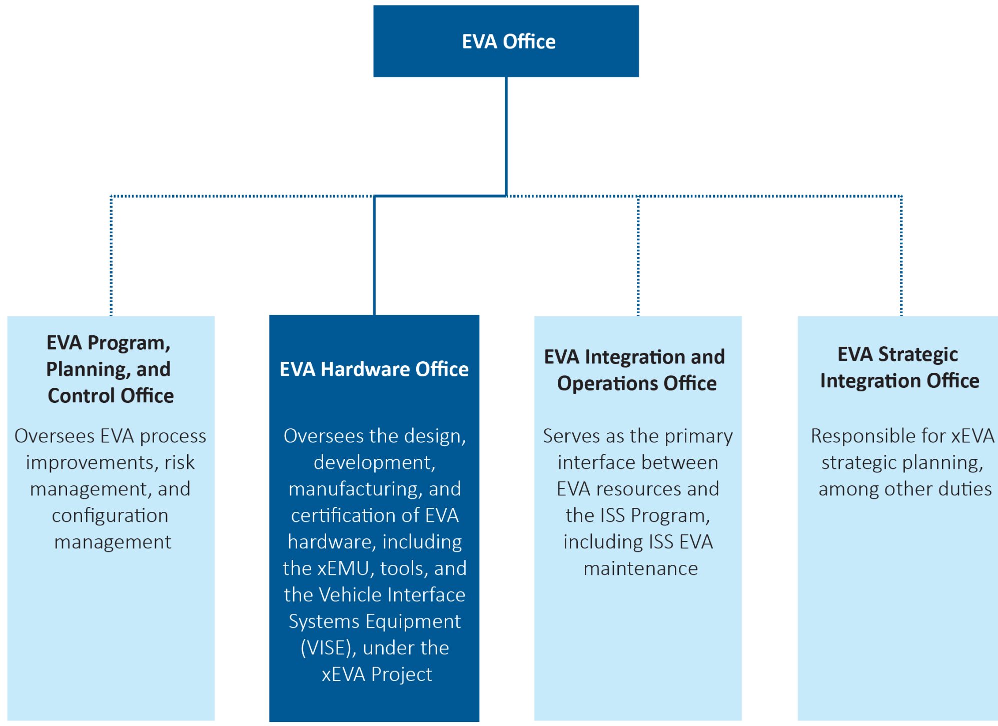
Figure 2: Spacesuit Management and Organizational Structure



Source: NASA OIG presentation of NASA information.

Within the EVA Office, four offices are responsible for managing the development of spacesuits through the xEVA Project. The EVA Office consists of the EVA Program, Planning, and Control Office; the EVA Hardware Office; the EVA Integration and Operations Office; and the EVA Strategic Integration Office. The development of the xEMU spacesuit falls under the xEVA Project within the EVA Hardware Office (see Figure 3).

Figure 3: Spacesuit Management and Organizational Structure



Source: NASA OIG presentation of NASA information.

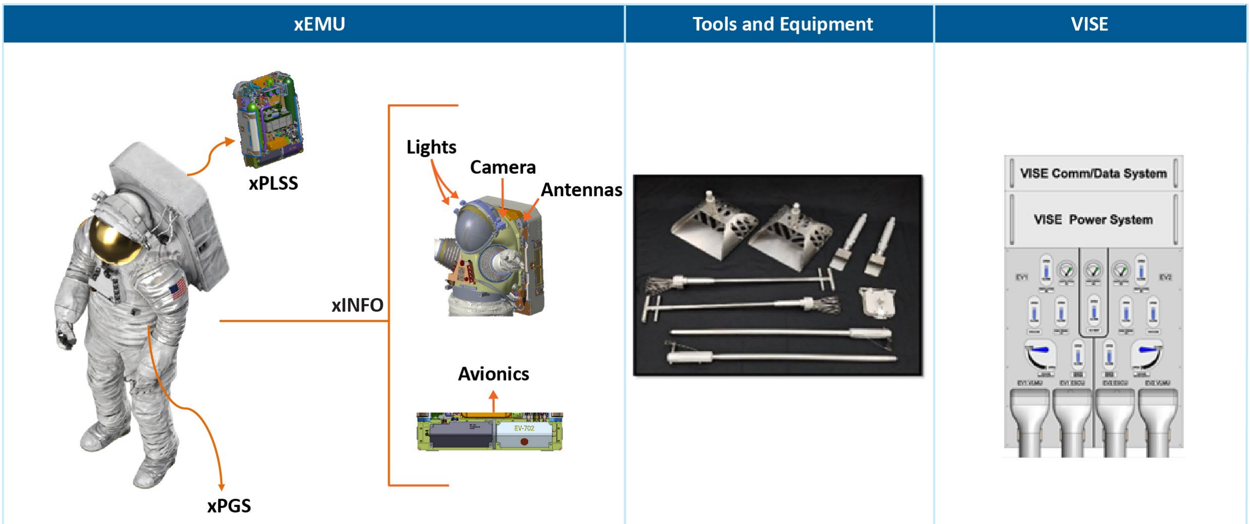
xEVA Project and Components

NASA's xEVA Project is designing and manufacturing the next-generation spacesuit, known as the xEMU, in-house, building from work conducted since 2007 to advance the technologies of the current extravehicular spacesuit developed by NASA and ILC Dover in 1990. The xEMU will feature a new design to accommodate a broader range of sizes and improve fit, comfort, and mobility. Specifically, the improvements include a highly mobile lower torso for walking and kneeling that will eliminate the "bunny hopping" astronauts experienced during the Apollo missions. As shown in Figure 4, the xEVA system is comprised of the xEMU, which includes the Exploration Portable Life-Support Subsystem (xPLSS), the Exploration Pressure Garment Subsystem (xPGS), and Exploration Informatics (xINFO) Subsystem; tools and equipment necessary to support extravehicular activities; and the Vehicle Interface to Suit Equipment (VISE).

Ground Prototype of the New Exploration Extravehicular Mobility Unit

Source: NASA.

Figure 4: xEVA System Components

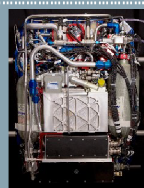
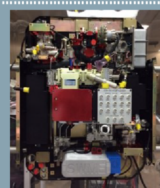
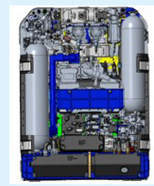
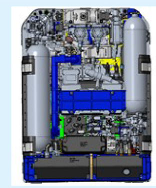
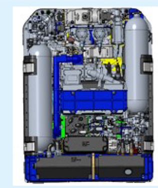


Source: NASA OIG summary of NASA information.

Exploration Portable Life-Support Subsystem

The xPLSS is an astronaut's life support system while outside the spacecraft. Worn like a backpack, the xPLSS provides the astronaut with oxygen, and removes carbon dioxide, odors, and humidity that build up inside the suit. The xPLSS also helps maintain body temperature by incorporating a fan to circulate oxygen. With a highly compressed set of technologies, the xPLSS is the most complex and expensive component of the xEMU. Figure 5 provides an overview of xPLSS development.

Figure 5: Planned and Completed xPLSS Development Activities

Completed	Completed	Completed	Planned	Planned	Planned
PLSS 1.0 (Breadboard) 2011	**PLSS 2.0 (Packaged GN2) 2012-2015**	**PLSS 2.5-301 (Electrical Live Loads) 2015-2017**	**xPLSS DVT Unit**	**xPLSS Qual Units**	**xPLSS Flight Units**
					
• Breadboard test unit • 397 hours of full PLSS operation	• Packaged lab unit • 25 EVAs, failure simulations, integration tests • 394 hours of unmanned PLSS operation • 291 hours of PLSS operation at vacuum • 200 hours of simulated EVA test time	• Partial build-up to test electrical systems	• Design Verification Test Unit • Design for 156 EVAs, 624 hours EVA • Unmanned EVAs in vacuum with simulated human metabolic processes • Pressurized launch/landing vibe testing	• Qualification Units • Design for 156 EVAs, 624 hours EVA • Test for 25 EVAs and 100 hours EVA Unmanned EVAs in vacuum • Full xEMU manned vacuum testing and thermal vacuum testing	• ISS xEMU Demonstration and Lunar 2024 Flight units • Flight Design with full flight controls for 100% oxygen human-rated usage • xEMU HLS Crew Training

Source: NASA OIG summary of NASA information.

Exploration Pressure Garment Subsystem

The remainder of the visible part of the spacesuit is known as the xPGS, which serves to maintain appropriate pressure around an astronaut's body to keep them alive in the vacuum of space while also providing mobility for physical operations. The xPGS is covered by a thermal material that insulates the astronaut, prevents heat loss, and protects the astronaut from micrometeoroids and other orbital debris that could puncture and depressurize the suit. The xPGS being developed for the xEMU also includes the Hard-Upper Torso, helmet, extravehicular visor assembly, shoulder joints, gloves, and boots. Underneath the xPGS, astronauts wear liquid cooling and ventilation garments through which cool water flows to help regulate body temperature.

Exploration Informatics Subsystem

The xINFO is comprised of the xEMU's avionics that promote crew autonomy during extravehicular activities, including high-definition video, worksite illumination, high-rate suit data recording, and associated antenna transmission and connection via electrical harnesses. Future upgrades to xINFO are anticipated after Artemis III.

Tools and Equipment

The xEVA system's tools include equipment used for physical support (handrails and walking aids), general lunar geology tasks (rake, sample collection bags, and scoop), construction activities (wrench, drill, and scissors), and other gear (dust mitigation tool kit and the U.S. flag).

Vehicle Interface to Suit Equipment

The VISE is a wall-mounted rack that allows a suit to interface with multiple spacecraft. The VISE connects the xEMU to vehicle fluids, power, suit/crew stabilization, data, and communications. The hardware is spacecraft-specific; therefore, NASA is currently customizing separate VISE units for the ISS and HLS.

Acquisition Strategies for Spacesuit Design and Development

In 2017, NASA decided to design, test, and produce xEMU suits in-house. As a result, the Agency would serve as the prime integrator of six suits built from components supplied by 27 different contractors and vendors (see Appendix B for more information):

- one design verification and testing (DVT) suit that will be used to test the design and features of the spacesuit before astronauts wear it,
- two qualification suits for parallel testing of the life support systems while being worn,
- one ISS Demonstration (ISS Demo) suit to be flight tested by ISS crew and remain on board the ISS for continued use, and
- two flight suits.

This is the first time in over 40 years that NASA has led the development of a completely new extravehicular spacesuit. As mentioned, NASA previously contracted with Hamilton Standard and ILC Dover to integrate and build the first EMU for the Space Shuttle Program. The Agency later partnered with Oceaneering International to develop the Constellation Program EVA Project from 2009 to 2016. The Agency planned to build six xEMUs with contractor and vendor support and then issue a contract for the production of additional suits. However, in April 2021 NASA shifted its proposed acquisition approach to use a services contract to support the initial build of all xEMU development and flight units.

Multiple Challenges to NASA's Development of Next-Generation Spacesuits Will Preclude a 2024 Moon Landing

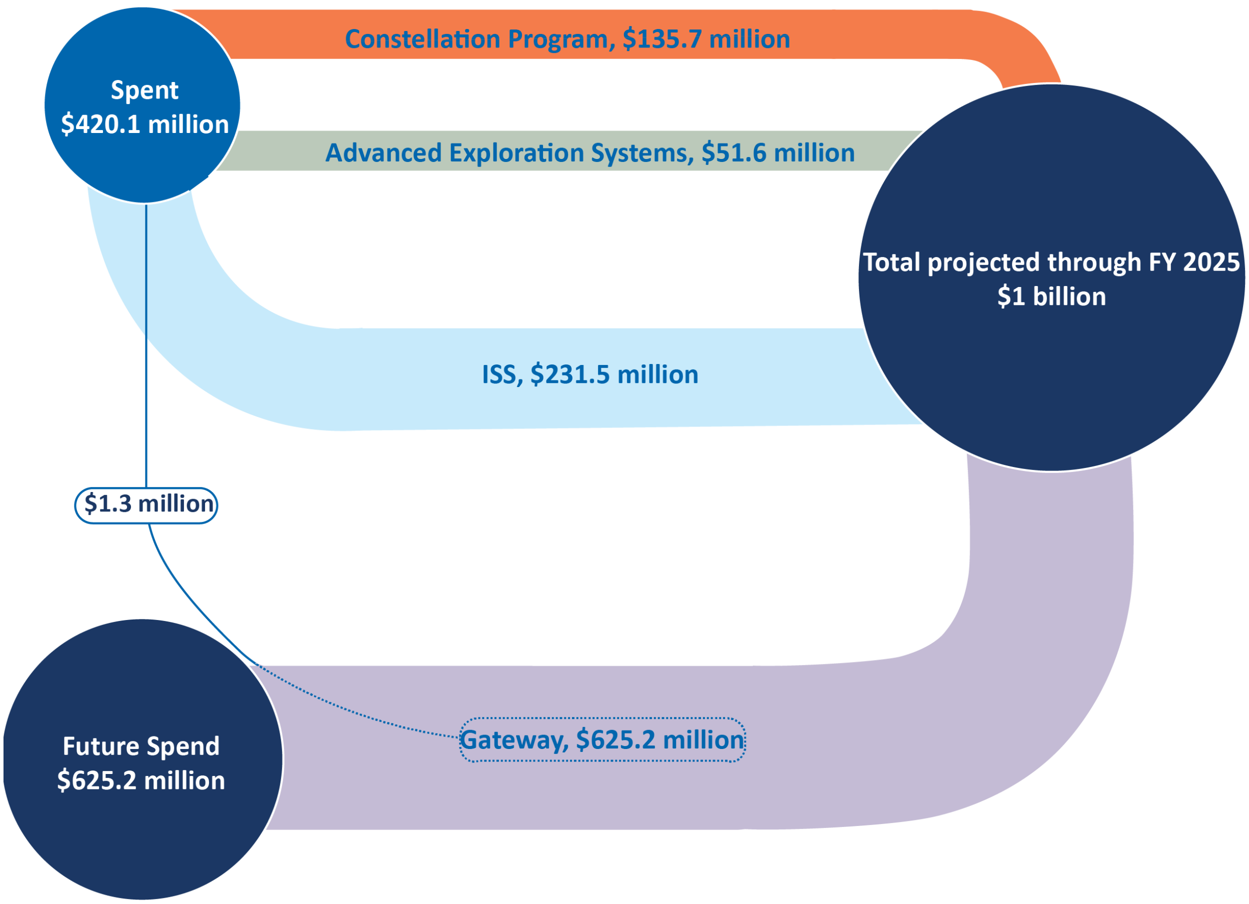
NASA's current schedule is to produce the first two flight-ready xEMUs by November 2024, but we found that the Agency will face significant challenges meeting this goal. This schedule includes an overall delay of approximately 20 months in delivery of the planned design, verification, and testing suit, two qualification suits, ISS Demo suit, and two lunar flight suits due to funding shortfalls, COVID-19 impacts, and technical challenges—delays that have left no schedule margin in the project. Given these challenges, we believe the current approach to spacesuit development will preclude a 2024 lunar landing. Looking ahead, evolving and competing requirements, including delivery date targets from key Program stakeholders such as the HLS, ISS, and Gateway increases the risk of future cost, schedule, and performance issues in spacesuit development and production. Moreover, by the time two flight-ready spacesuits are completed, NASA will have spent over a billion dollars on the development and assembly of its next-generation spacesuits.

NASA Will Spend Over $1 Billion Before the First Two Next-Generation Spacesuits Are Ready for Flight

Since 2007, NASA has spent about $420.1 million on spacesuit development. Going forward, the Agency plans to invest approximately $625.2 million more, bringing the total spent on design, testing, qualification, an ISS Demo suit, two flight-ready suits, and related support to over $1 billion through fiscal year (FY) 2025, when the first two flight-ready spacesuits will be available based on current xEVA schedules.[12] As shown below, over these last 14 years the financial responsibility for next-generation spacesuit technology development has been borne by several different NASA programs: Constellation, Advanced Exploration Systems Division, and ISS. However, in FY 2020 the financial responsibility for the xEVA Project transferred to the Gateway Program. Figure 6 summarizes spending on spacesuit development as of December 2020.

[12] The total future spending of $625.2 million was calculated by using the FY 2021 President's Budget Request for FY 2021 through FY 2025, with FY 2021 prorated based on costs through December 2020. Related support includes vehicle support hardware, training hardware and facilities, testing facilities, and extravehicular activity tools. This funding also includes future suit production costs.

Figure 6: Total Planned Spending on xEVA FY 2008 through FY 2025, as of December 2020



Source: NASA OIG presentation of NASA information.

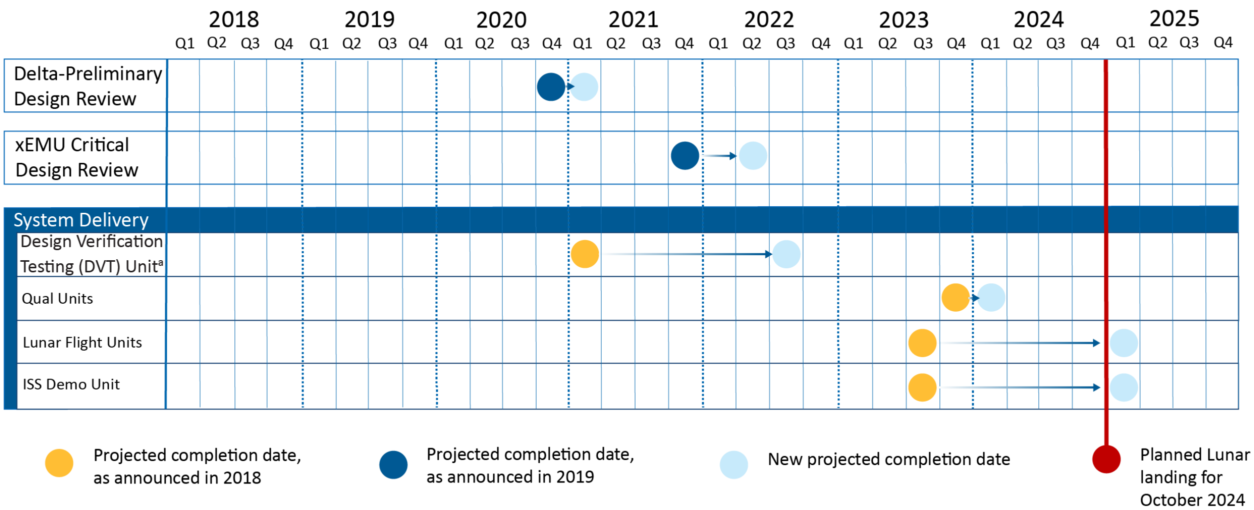
Delays in Spacesuits Development Will Preclude a 2024 Moon Landing

Prior to 2019, NASA's schedule for designing, testing, and developing the xEMU was to provide flight-ready spacesuits to the ISS by 2023 and to the Artemis III mission by 2028. However, when the timeline for the Artemis III lunar landing was accelerated to 2024, NASA was required to fast-track its schedule by 4 years. In preparation for the Artemis III mission, in 2019 NASA required the xEVA Project to deliver human-rated xEMU flight suits to the HLS Program for integration no later than March 31, 2023.[13] As of March 2021, that date has been delayed 20 months to November 2024 due to reduced funding for spacesuit development in FY 2021, COVID-19 impacts, and ongoing technical issues.

[13] According to NASA Procedural Requirement 8705.2B, *Human-Rating Requirements for Space Systems* (May 6, 2008), human-rating is the certification granted to crewed space systems prior to the first crewed flight to ensure the system can safely carry astronauts by accommodating human needs, effectively utilizing human capabilities, controlling hazards with sufficient certainty to be considered safe for human operations, and providing the capability to safely recover from emergency situations.

In early summer 2020, the xEMU's delta-Preliminary Design Review experienced a 3-month delay to September 2020.[14] The next major milestone, the xEVA system-level Preliminary Design Review, is scheduled to take place in October 2021. Figure 7 shows schedule delays for each of the suit deliveries. NASA expects the xEVA Project to experience further delays but given the slippage to date the Project has no remaining schedule margin to address the impact.

Figure 7: xEMU Schedule Adjustments by Fiscal Year (as of March 2021)



Source: NASA OIG presentation of Agency information.

[a] The slip for the DVT unit was due, in part, to additional requirements needed to ensure an Artemis capable xEMU.

Funding Issues

For FY 2021, Congress approved 77 percent of the total amount NASA requested for the Gateway Program. As a result, Gateway Program officials reduced funding for the xEVA budget from a planned $209 million to $150 million (a 28 percent decrease), resulting in at least a 3-month delay to the xEMU development schedule. As a result, NASA was unable to procure the xPGS components for the DVT suit and long-lead hardware for the qualification suit at the beginning of FY 2021 as originally planned. Absent receiving an additional $9.3 million in FY 2021, the xEVA Project is considering eliminating the second qualification xEMU suit, which would result in an additional 6- to 9-month delay for delivery of the Artemis III lunar suit and a 3-month slip for delivery of the ISS Demo suit. If funding continues below projected amounts beyond FY 2021, the schedule will slip further, resulting in additional future cost growth as the time needed to complete work and deliver the new spacesuits stretches beyond 2024.

[14] Preliminary Design Review is one of a series of checkpoints in the design life cycle of a complex engineering project before hardware manufacturing can begin. As the review process progresses, details of the vehicle's design are assessed to ensure the overall system is safe and reliable for flight and meets all NASA mission requirements prior to entering the detailed design phase known as Critical Design Review. A delta-Preliminary Design Review is an optional checkpoint to address design updates between Preliminary Design Review and Critical Design Review.

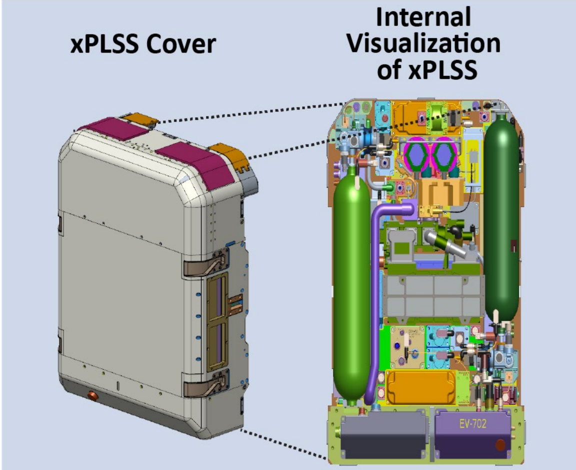
COVID-19 Impacts

The full effects of COVID-19 pandemic closures and delays on the spacesuit development program have yet to be identified. However, the xEVA Project experienced at least a 3-month delay as a result of intermittent facility closures and in-person work restrictions beginning in March 2020 that were ongoing as of March 2021.

Technical Challenges

Assembly of the DVT suit has experienced numerous technical challenges related to the xPLSS that have contributed to schedule delays.

- The circuit boards of the xPLSS controllers required rework to update the Caution and Warning System, the avionics that control the critical life support components. One such capability—Space-to-Space Exploration EMU Radio—was updated with a function to ensure any non-critical failures from the xEMU avionics system will not lead to critical failures on the communications system.
- The xPLSS's flight-like Display and Control Unit, which the astronauts use to control all critical functions, experienced production delays. Initially, NASA built a prototype using commercially available products to determine the correct sizing. Due to design changes and upgrades through the development process, NASA personnel swapped the unit for an existing backup unit that provided appropriate functionality for testing.
- In March 2021, the DVT suit assembly process was placed on hold due to a component failure. Specifically, staff used the wrong specifications to build a complicated xPLSS interface and its failure demonstrated shortcomings in the DVT development process. NASA personnel attributed this issue to (1) schedule pressure; (2) reliance on the previously utilized test box; (3) a communication breakdown among the team; (4) rapid growth of the project team, including the addition of inexperienced personnel; and (5) the use of an unreleased drawing during development testing.



Source: NASA

Additionally, the schedule for the xEVA VISE units—the HLS vehicle hardware required to ensure integration with the spacesuits—continued to slip as NASA delayed selection of the HLS vehicle contractors.[15] The down-select, originally scheduled for October 2020, was delayed 7 months until April 2021 when NASA chose the Space Exploration Technologies Corporation's (SpaceX) Starship as the

[15] On April 30, 2020, NASA selected three companies—SpaceX, Blue Origin, and Dynetics Incorporated—to begin human lander design efforts for NASA's HLS Program for Moon missions. On April 16, 2021, NASA selected SpaceX's Starship to continue past design and develop the first commercial human lander for Artemis III to carry the next two American astronauts to the lunar surface. However, NASA officials said other companies can compete for future missions.

lander for the Artemis III lunar landing mission.[16] Prior to the selection of the SpaceX lander, NASA was customizing three separate VISE units for the three HLS spacecraft in design phase. Current schedule projections show the VISE flight units will not be delivered to the HLS Program for integration and testing until January 2025—a delay of nearly 2 years from the originally planned date of March 2023. As a result, at the current budget levels and based on past development trends, the xEVA system for SpaceX's Starship will not be available for a late 2024 Artemis III launch.

No Schedule Margin Remains to Meet 2024 Delivery Goals

Compounding NASA's schedule challenges is the lack of any schedule margin for the xEVA Project to support two xEMU flight suits and VISE units for a 2024 lunar landing.[17] The funding shortfalls, COVID-19 Center closures, and technical challenges previously discussed eliminated the xEVA Project's schedule margin of approximately 12 months, which represented xEVA's plan to provide the flight suits to the HLS Program by March 2023 and HLS's need-by date of April 2024. Once the hardware is completed, the HLS Program needs 6 to 10 months for integrating the hardware into the lunar landers prior to flight. As of March 2021, the lunar suits are now scheduled to ship from Johnson Space Center to Kennedy Space Center in November 2024—8 months after the HLS Program's "need" date. Given the integration requirements, the suits would not be ready for flight until April 2025 at the earliest making the xEVA system unavailable for the currently scheduled late 2024 lunar landing. As of June 2021, NASA had no contingency plans if the suits are not ready. Likewise, continued delays in other major Artemis components like the Space Launch System and HLS would also preclude a 2024 lunar landing.[18]

[16] On April 26, 2021, Blue Origin and Dynetics Incorporated formally protested NASA's HLS award to SpaceX, and on July 30, 2021, the protest was denied. In May 2021, the Senate Commerce Committee approved the 2021 NASA Authorization Bill that includes a requirement for NASA to fund HLS design, development, testing and evaluation "for not fewer than 2 entities." The directive to select a second HLS vendor, if enacted, will affect the VISE schedule as additional work would be required to design and develop VISE units for multiple landers.

[17] Space flight projects routinely encounter technical difficulties during development that cause delays; therefore, it is a best practice to build extra time or margin into the project schedule. NASA OIG, *NASA's Management of the Gateway Program for Artemis Missions* (IG-21-004, November 10, 2020).

[18] We previously reported on the challenges associated with Space Launch System and HLS development in meeting the Agency's 2024 lunar landing goals: NASA OIG, *Artemis Status Update* (IG-21-018, April 19, 2021).

Evolving and Competing Requirements Increase the Risk of Future Cost, Schedule, and Performance Issues

The next-generation spacesuit must be able to support (1) the Artemis missions (including the HLS), (2) the ISS, (3) the Orion capsule, and (4) the future Lunar Gateway. However, these programs are in varying phases of design and development and have specific technical requirements.[19] As a result, xEVA system development faces increased cost, schedule, performance, and safety risks. At the same time, NASA is struggling with competing HLS and ISS schedules as the HLS Program needs the xEMUs for the 2024 Moon landing, but the ISS Program needs the suits to replace the 45-year-old EMUs currently in use on the Station.

Evolving Requirements Increase the Risk of Cost and Schedule Growth

To meet the goal of landing humans on the Moon by 2024, the Agency must first develop the HLS and complete development of an xEVA system that is compatible with the lander. The schedule acceleration for a Moon landing forced the xEVA Project to condense its timeframe, which has led to concurrent testing and development efforts. Additionally, the xEVA Project is much further along in development than the HLS Program, leading to a design maturity mismatch that has already impacted the xEVA Project's mass requirements and will likely further impact the Project as the HLS Program matures and additional requirements are further defined.

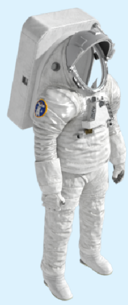
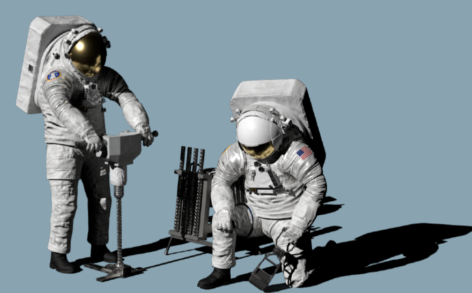
Concurrency in Development and Testing

NASA originally planned for the xEMUs to be designed, tested, and developed through an incremental approach. For example, earlier schedules called for testing the xEMU ISS Demo suit on the ISS prior to producing the flight suits. However, we reported in 2017 that given the already tight development schedule, NASA was at significant risk of the xEMU prototype not being sufficiently mature in time to test it on the ISS prior to 2024.[20] With the acceleration of the Artemis Program in 2019, NASA pushed out delivery of the ISS Demo suit until after the estimated delivery of the flight suits. This schedule adjustment increases the risk of costly rework for the xEMUs since key life support system capabilities of the suit will not have been previously demonstrated in space. The ISS Demo suit will test key technologies such as ventilation, thermal regulation, power, system controls, garment cooling, and waste management. Even though NASA anticipated that full development of the xEMU for use beyond low Earth orbit would occur well after the ISS Demo suit, as of March 2021 assembly and testing of these systems will be concurrent. Figure 8 provides the capability upgrades from the EMU to the ISS Demo and xEMU.

[19] Although the Orion Program is not considered a stakeholder program like the Gateway, HLS, and ISS programs, and thus does not have technical requirements that the spacesuit must consider, the Orion capsule is a key element in certain contingency scenarios involving the spacesuit as discussed later in this report.

[20] IG-17-018.

Figure 8: Comparison of EMU and ISS Demo/xEMU Capabilities

	EMU	ISS Demo/xEMU[a]
		
Operating Pressure	4.3 psi	4.3 to 8.2 psi
Maximum EVA Time	7.5 hours	9 hours
Mobility	Restricted to upper torso and limited movement in the lower torso	Allows for upper torso and full lower torso movement (walking spacesuit)
Sizing	Fits a limited portion of the population	Fits the majority of the population
Mass	Requires increased consumables and support systems	Lower system mass enabling missions beyond low Earth orbit
Spacesuit Entry	Waist entry	Rear entry
Operating Environment	Low Earth orbit and microgravity	Low Earth orbit, microgravity, cislunar[b], and lunar surface
Communications and Informatics	Communications cap that provides ultra-high frequency radio for voice, limited suit telemetry, and EVA data and high-definition camera demonstration	Integrated audio with ultra-high frequency and WIFI for voice and high-rate telemetry, high-definition cameras, and high-speed data capture
Maintenance/Upgrades	Designed for ground maintenance and ground component upgrades only	Modular design to allow for inflight maintenance and component upgrades

Source: NASA OIG summary of NASA information.

[a] ISS Demo and xEMU capabilities are the same with the exception of specific lunar boots for lunar surface missions.

[b] Cislunar generally refers to the space between Earth and the Moon. Cislunar space includes low Earth orbit, medium Earth orbit, geosynchronous Earth orbit, and other orbits, such as low lunar orbit and near-rectilinear halo orbit, the intended orbit for the Gateway.

HLS and xEVA System Design Maturity Mismatch

NASA's design and development of the xEVA system for Artemis missions relies heavily on the requirements of the HLS Program. The xEVA system must be compatible with the HLS landers because the landers will support the suit while on the lunar surface. In addition, the astronauts will need to wear the suits for long periods of time while in the landers during descent to the lunar surface and ascent to lunar orbit. However, while NASA has spent more than a decade designing and developing components of the xEVA system, the HLS Program remains in its early design phase. The immaturity of the HLS Program presents a challenge for NASA to ensure the suits are compatible with HLS hardware, software, and operational parameters. Gateway Program officials have expressed concern that because the xEMU is so far ahead of the lunar landers in terms of development, there is risk that design assumptions made by the xEVA Project will not be appropriate for the landers. This is especially true regarding the xEMU mass and materials used, the xEMU boot design based on the lunar landing location, and the VISE system specific to each landing vehicle.

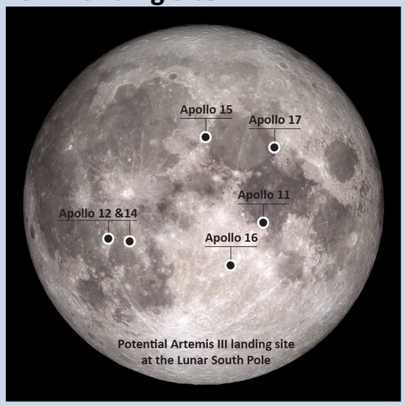
Mass Constraints for xEVA System. Mass, as it relates to the HLS lander requirements, is one of the biggest challenges facing the xEVA system. In May 2020, one xEMU was estimated to weigh 183.6 kilograms (404.8 pounds), which fit within the HLS mass maximum at the time of 186.6 kilograms (411.4 pounds). However, in June 2020 the xEVA Project agreed to new mass requirements for the HLS landers that decreased the mass allocation for the xEMU by 9.5 kilograms (20.9 pounds) to 177.1 kilograms (390.4 pounds), meaning the current spacesuit design no longer fits within HLS constraints. According to xEVA Project officials, expected design updates could put the Project on trajectory to meet the HLS mass requirements, but these efforts may be hindered by the FY 2021 budget reduction previously mentioned. Because the xEVA Project does not currently have funding available to invest in newer, lighter weight materials, such as for the xEMU's Hard Upper Torso, the Project may have to revert to materials that are historically proven but heavier. NASA is also considering ways to reduce the overall mass of the xPLSS—the heaviest component of the xEMU.

The VISE may also not meet project mass constraints. As of February 2021, the current mass estimate for the VISE is 106.0 kilograms (233.7 pounds), which exceeds the xEVA system's allocation for VISE of 94.9 kilograms (209.2 pounds). However, unlike the xEMU, VISE is still in the early stages of development, which will allow the xEVA Project to explore options for controlling mass.

The HLS mass requirements could also potentially impact future development of the xEVA system, specifically for astronaut lighting and communications needs during lunar surface exploration. In addition to the lighting provided by the lander, the xEMU helmet illuminates the immediate area around the spacesuit; however, as astronauts travel out of sight of the lander, this suit-based lighting might not be adequate to navigate a path to and from the lander. Program officials are examining options to increase the xEMU's lighting capability including handheld, suit-mounted, or deployed lights. Regarding communication, as long as astronauts are within range of the lander they will be able to communicate with Earth because of the communications system—that is, the VISE—on board the lander, but that capability decreases as astronauts travel further from the lander. For early Artemis missions, the communication range capability for the xEMU will be 500 meters, but NASA is exploring options to expand that to 2,000 meters while weighing the impact such an expansion would have on spacesuit and HLS requirements. Options to extend the communication range for the xEMU include deploying communication relays on the lunar surface. However, given the current mass constraints for the lander, transporting additional equipment to increase lighting and communication capabilities could prove challenging.

Official Landing Site Affects Boot Development. NASA has not formally announced the official landing site for the Artemis III mission, but the Moon's South Pole is a leading location in addition to a potential return to the Apollo landing sites near the Moon's equator. Regardless of the landing site, the xEMU's boots will need to be adjusted accordingly to ensure safety of the astronauts. For example, the permanently shadowed region of the Moon's South Pole has extreme temperature swings, as such the boots will need to transition from the moderate environment of the lander to the harsh environment of the South Pole and back again. According to NASA officials, designing boots that will be operational in this extreme environment will be a challenge as access to suitable materials is limited and the technology needed to help address this challenge is still being tested. In 2020, NASA awarded multiple contracts to Final Frontier Design to develop xEMU components, including the boots and hip and waist joints.

Apollo Landing Sites and Potential Artemis III Landing Site



Source: NASA OIG presentation of Agency information.

Designing a VISE for Three Landers. As previously discussed, the final design and development of the VISE depends on the requirements of the lunar lander. Until April 2021, when NASA selected SpaceX's Starship, NASA had continued to invest in the design of three different VISE systems to meet the differing requirements of the individual landers, therefore extending the xEVA Project schedule by 7 months and costing NASA about $600,000 in additional VISE costs.

Continued Use of Aging Spacesuits on ISS Will Require Costly Maintenance in the Face of Continuing Safety Risks

In 2017, we reported on NASA's need to replace the aging EMU fleet so astronauts can safely continue ISS missions through 2024.[21] Given the potential extension of ISS operations through 2030, the need to replace the EMU suits has increased significantly.[22] The modern-day EMU was developed in 1978 during the Space Shuttle Program and, in the decades since, the spacesuit has been maintained to extend its usability decades beyond its initial 15-year lifespan. The Agency is managing the design and health-related risks associated with the EMUs, including the constrained Hard Upper Torso sizing that limits which astronauts can participate in extravehicular activities. Among the ongoing risks, we documented in our 2017 report broad categories of significant incidents including dangerous water intrusion and carbon dioxide problems. NASA is also tracking two other primary risks: decompression sickness and thermal regulation. In addition, the spacesuits have caused astronaut shoulder and hand injuries and have failed to provide sufficient nutrition and hydration while in use. Further, over the past 2 years, the Aerospace Safety Advisory Panel has recommended NASA immediately transition the EMU to the xEMU system, cautioning that continued use of the aging suits is too risky for astronauts.[23] The Panel noted that NASA

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[21] IG-17-018. We recommended that the Agency conduct a trade study comparing the cost of maintaining the current EMU spacesuit and developing and testing a next-generation spacesuit. The Agency responded with an analysis comparing cost impacts to the budget for continued sustainment of the EMU to 2028 as well as potential EMU replacement options.

[22] 51 U.S.C. § 70907(b)(3). ISS operations are currently authorized through September 2024, but several legislative proposals provide for extending Station operations through 2030.

[23] Aerospace Safety Advisory Panel Reports for 2019 and 2020.

has had difficulty upgrading the EMUs due to the loss of component vendors over time and lack of critical refurbishment parts. Even though NASA agreed with the Panel, the accelerated timeline for landing on the Moon gave rise to conflicting priorities with the Artemis Program. If the HLS Program receives the first two xEMU flight suits in November 2024, the ISS Program will be further delayed in obtaining needed replacements.

Of the original 18 flight Primary Life-Support System (PLSS) units, only 11 remain in inventory to support the ISS Program, with typically 4 of these units on the ISS at any one time. Tasked with providing life support to astronauts while wearing the EMU on spacewalks, the PLSS is the most complicated and expensive component of the spacesuit. Maintenance of these 11 units currently costs about $150 million a year under a contract with Collins Aerospace set to expire in 2024. Therefore, NASA will need to complete development of the ISS Demo suit as soon as possible to begin transitioning from the EMU to the xEMU.

Gateway xEMU Dormant Storage Risk

Looking beyond 2024, NASA continues to track a risk affecting the compatibility of the xEMU with the Gateway Program. Once operational, the Gateway will have periods of dormancy of up to 3 years without services or human interaction, during which time the xEMU will be held in inactive or dormant storage. In comparison, EMUs are regularly used on the ISS and maintenance is performed on the suits both on the Station and when a spacesuit is returned to Earth after 6 years or 25 spacewalks. While the Gateway Program requires a potential 3-year dormancy period, the xEVA system requirement for dormant storage is 2 years, resulting in a mismatch between the Gateway Program and xEVA Project requirements. To prepare for the Artemis lunar missions and help address the uncertainty around dormant storage, a mini-version of the xEMU's xPLSS will experience a 6-month dormant period on the ISS as part of the Agency's Spacesuit Evaporation Rejection Flight Experiment (SERFE). Delivered to the Station in October 2020, SERFE will conduct a series of 25 simulated spacewalks over the course of a year to test the xEMU's temperature control component of the mini-PLSS.[24] Prior to being sent to the ISS, the mini-PLSS also experienced a dormant period between June and October 2020. Lessons learned from these tests will be used to improve the design of the xEMU and mitigate the risks associated with longer-term dormant storage. NASA has also contracted with Aerospace Corporation to conduct additional testing and analysis to determine if the xEMU can handle the Gateway storage requirement.

Gateway and Orion Contingency Scenario Risks

NASA has developed contingency scenarios that outline how crew will transfer between HLS and Gateway or Orion in the event of a hard dock failure or depressurization event. However, these contingency scenarios may be outside of the "operational baseline"—that is, the planned configuration of HLS, Gateway/Orion, and the xEVA system during standard operation—and may preclude the safe transfer of crew.

- *Contingency Transfer to Gateway.* During descent to or ascent from the lunar surface, crew will be required to wear a pressurized, non-xPLSS, xEMU configuration known as Vehicle Loop Mode. While in Vehicle Loop Mode, the xEMU receives life support, power, and data directly

[24] The main objective of SERFE is to evaluate the mini-PLSS's active thermal control systems, including the Spacesuit Water Membrane Evaporator (SWME), which provides cooling and ventilation for the xEMU. The SERFE tests will simulate crew metabolics to see how the mini-PLSS, including the SWME, will react in different scenarios, such as a low Earth orbit spacewalk or a lunar walk on the Moon's surface.

from the HLS rather than the xPLSS. This requires the suit to be hooked up to umbilicals; however, in the case of an HLS depressurization event, the crew may not be able to safely egress from HLS to Gateway due to umbilical interference and length, a scenario that could lead to loss of crew. To mitigate this risk, the xEVA Project is coordinating contingency working groups with the Gateway Program Office to develop processes that would allow crew to transfer between HLS and Gateway unsuited, including determining the amount of time necessary to repress or feed the air leak or potential design changes for the spacesuits, HLS, and/or Gateway.[25]

- *Contingency Transfer to Orion.* In the event of a hard dock failure with Orion or depressurized and toxic HLS cabin, crew may be required to perform a docked transfer from the HLS to Orion.[26] However, there is the possibility that the current planned hardware configuration of the HLS, Orion, and xEVA system would not allow for a safe transfer, leading to potential loss of crew. Specifically, NASA found that when wearing the xPLSS, crew will not fit through Orion's docking tunnel. Currently, options to mitigate this risk include investigating the feasibility of an external transfer between Orion and HLS.

Limited Coordination Across Stakeholders Coupled with Hardware Availability Hinder Training Schedules

Prior to their use on ISS and Artemis missions, astronauts will require suits for training. The Flight Operations Directorate (FOD) is responsible for training crew in how to use suit hardware and associated tools. FOD plans to use xEMU suit components as training hardware beginning approximately two years before flight, followed by an xEMU qualification or flight suit within a year before flight. However, xEMU's suit hardware may not be available when needed for training. This issue exists regardless of whether the new spacesuits will be provided to the ISS to replace the aging EMUs or to HLS for Artemis III, as previously discussed. Therefore, we found that the training needs across the stakeholders—namely, the ISS and HLS programs—do not align with EVA Office's projections of when suit hardware will be available.

For the transition from the EMU to the xEMU on the ISS, the current ISS Program schedule shows FOD beginning astronaut training with the training hardware as early as March 2022.[27] At the same time, FOD anticipates training to begin in May 2022 to support the Artemis III lunar surface mission currently scheduled for October 2024.[28] Nonetheless, the EVA Office has identified a risk that there will not be sufficient quantities of training hardware available for these early training events and, as a result, there is a potential of prolonged training efforts.

For Artemis III lunar lander-related training, FOD has scheduled a 12-month training period, beginning in October 2023, using an xEMU flight suit or qualification suit to support EVA crew-specific training in a

[25] "Feeding the leak" means to supply enough additional oxygen to counterbalance the effects of the air leak and maintain pressure within the vehicle and/or spacesuit.

[26] Docking occurs when one spacecraft, such as the HLS, rendezvous with another spacecraft, such as the Orion capsule. A hard dock occurs when an air-tight connection between the spacecraft is established. As such, a hard dock failure happens when this air-tight connection between the spacecraft does not occur.

[27] ISS-related training will include pressurized operations, umbilical access, suit mounting, and donning and doffing. Training will take place in Johnson Space Center's Neutral Buoyancy Laboratory, an underwater training facility that helps prepare astronauts for zero-gravity conditions.

[28] Artemis III lunar surface-related training will include operations related to extravehicular and intravehicular activities, operating in Vehicle Loop Mode without the xPLSS, and utilization of a new informatics display.

vacuum chamber event.[29] If the qualification suit is delivered on time, this would allow for an uninterrupted training schedule for the Artemis III mission. The HLS Program anticipates beginning crew training in the lander using the xEMU flight suit in April 2024, 6 months before the planned October 2024 launch date.[30] Nonetheless, the EVA Office will not deliver the flight suits until at least November 2024, a month after the planned Artemis III launch date.

In our judgment, these misaligned schedules between the EVA Office, FOD, ISS Program, and HLS Program are the result of inadequate coordination across these different offices due, in part, to the lack of an integrated master schedule focused on astronaut training needs. Both GAO and NASA policy recommends the use of an integrated master schedule as a best practice to better manage timing and align tasks across project activities.[31] An integrated master schedule allows Agency officials to evaluate schedule risks and identify early warnings of schedule slips. Without a schedule that identifies hardware deliveries, training requirements, and potential schedule risks, NASA management will face difficulties in coordinating astronaut training needs with suit availability across missions.

NASA Pivots with New Proposed Acquisition Approach for Next-Generation Spacesuits and Future Extravehicular Activity Services

As NASA continues the development and maturation of the xEVA system capabilities, the Agency is considering how to approach the procurement of additional suits for both the ISS and Artemis missions. In October 2019, NASA issued a Request for Information (RFI) to determine industry capabilities in terms of production and fulfillment of future spacesuit needs.[32] At that time, NASA intended to initiate a hybrid contract approach that consists of a single prime contractor for integration and multiple awards for development and sustainment known as the Exploration Extravehicular Activity Production and Services (xEVAPS) contract. That is, after NASA finished developing the new spacesuit in-house, the Agency would contract with industry for system production. However, after 18 months NASA canceled the xEVAPS RFI and issued a new RFI in April 2021 for the Exploration Extravehicular Activity Services (xEVAS)—significantly altering its approach for future suit production.

The xEVAS RFI proposes a commercial services approach to acquiring extravehicular activity capabilities for the ISS and Artemis programs. Under this approach, NASA will pay to use contractor-developed suits instead of building the xEMU qualification and flight suits in-house or purchasing extravehicular suits from a contractor. Historically, NASA has relied on government-owned hardware to provide

[29] FOD utilizes an "L minus" system to calculate training need dates, with the "L" signifying the Artemis III launch date. For example, with the assumption of an October 2024 launch date, FOD has determined that training with the qualification suit components would begin 12 months prior to the Artemis III launch, or October 2023.

[30] HLS lander-specific training will include those related to mobility (climbing a ladder, donning/doffing, fall protection), suit storage, and contingency scenarios.

[31] NASA/SP-2010-3403, *NASA Schedule Management Handbook*, January 2010, states the integrated master schedule is developed by defining and sequencing tasks/milestones, estimating task/activity durations, documenting constraints, and considering resources. GAO *Schedule Assessment Guide, Best Practices for Project Schedules* (GAO-16-89G, December 2015) states that the integrated master schedule should be the focal point of program management as the document that integrates the planned work, the resources necessary to accomplish that work, and the associated budget.

[32] RFIs may be used when the government does not presently intend to award a contract but wants to obtain price, delivery, other market information, or capabilities for planning purposes. FAR 15.201, *Exchanges with Industry Before Receipt of Proposals*.

extravehicular activity capabilities; however, according to EVA Office officials, the xEVAS approach is in keeping with NASA's goals of nurturing the commercial space industry and follows a similar model utilized by the Agency's commercial crew and cargo efforts.[33] See Table 1 for a comparison of the xEVAPS and xEVAS RFIs that identified possible commercial approaches to procurement.

Table 1: Comparison of xEVAPS and xEVAS Approaches to Procuring Next-Generation Spacesuits

xEVAPS Deliverable Approach	xEVAS Services Approach
Procurement Process	
• NASA develops and builds 1 ISS Demo suit and 2 Artemis III flight suits in-house, then transitions future production and sustainment to private industry. • Industry builds additional spacesuits based on NASA's design.	• NASA procures 1 or more commercial extravehicular activity service(s) with demonstration as early as 2024. • NASA continues to design, develop, and mature the xEMU through Critical Design Review.
NASA's Estimate of Suits Needed	
Deliverables for training: • At least 2 xPGS training suits per year (with the capacity of building up to 4 training suits). • At least 1 vehicle interface equipment training unit per year (with the capacity of building up to 3 training units). • At least 1 toolkit per year (with the capacity of building up to 3 training units). **Deliverables for in-flight use:** • At least 2 xEMU flight suits per year (with the capacity of building up to 4 flight suits). • At least 1 vehicle interface equipment unit per year (with the capacity of building up to 3 units). • At least 1 toolkit per year (with the capacity of building up to 3 units).	**Service-based suits for in-flight use:** • 6 ISS suits (4 of the suits will be used on the Station and 2 will be kept on Earth as spares). • 16 lunar suits (the Artemis program will get 14 lunar suits and the Gateway Program will get 2 lunar suits).

Source: NASA OIG summary of Agency xEVAPS RFI and xEVAS RFI information and related presentations.

[33] Since 2010, NASA has partnered with Boeing and SpaceX to develop commercial crew capabilities, and since 2008 the Agency has partnered with Orbital ATK and SpaceX for its commercial cargo resupply efforts. Beginning in 2016, Sierra Nevada was added to the commercial cargo resupply effort. As of June 2018, Orbital ATK was acquired by Northrup Grumman and was renamed Northrup Grumman Innovation Systems.

As previously discussed, over the past 14 years NASA has invested $420 million in next-generation spacesuit development. Currently, NASA plans to continue design, development, and maturation of the xEMU through Critical Design Review—currently scheduled for spring/summer 2022—while also pursuing the xEVAS.[34] However, even though NASA will provide access to xEMU technical data, the xEVAS RFI does not require potential contractors to utilize any of this data for their spacesuit development. Instead, NASA will give industry the choice to either leverage NASA designs or propose their own designs. Therefore, it is unclear to what extent NASA's $420 million investment to date will be utilized. Additionally, although highly desired, the xEVAS RFI does not stipulate that the suit be compatible with both the ISS and Artemis programs. This could result in industry developing (and NASA purchasing) two different spacesuits—one for use in low Earth orbit on the ISS and another for use on the lunar surface for Artemis missions. However, developing a suit solely for the ISS may not be cost effective given the Station's limited expected lifespan.[35]

Regardless of NASA's approach for next-generation spacesuits and extravehicular activity services, future contractors will need to provide suits that are compatible with the ISS, Gateway, and HLS for future Artemis missions.[36] However, with the evolving and competing requirements of the xEMU's stakeholder programs and the Agency's uncertainties about mission priorities, NASA is at risk of awarding a contract without clearly defining key technical requirements. Additionally, NASA has yet to formalize its acquisition strategy for next-generation spacesuits. According to federal guidance, agencies are required to perform acquisition planning, including identifying the milestones in which decisions are made and addressing all the technical, business, management, and other significant considerations that control an acquisition.[37] Awarding a contract before technical requirements and an acquisition strategy are solidified could result in numerous modifications to the contract, increasing cost and schedule. As our prior work has shown, entering a contract before completing development work can exacerbate cost and schedule risks, particularly if issues are discovered late in the development effort and require costly rework.[38]

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[34] A Critical Design Review demonstrates that a program or project design is sufficiently mature to proceed to full-scale fabrication, assembly, integration, and testing and is considered a key step in the development process because it often reveals shortcomings that must be addressed before the spacecraft design is finalized and manufacturing begins.

[35] The ISS is currently scheduled to be retired in 2024 but is anticipated to be extended to at least 2030. 51 U.S.C. § 70907(b)(3).

[36] Initially, the HLS Program requires two xEMUs while the ISS Program requires four. Additional suits will also be needed to ensure spares are available for each program.

[37] FAR 7.102, *Policy*, requires that agencies perform acquisition planning and conduct market research for all acquisitions in order to promote and provide for acquisition of commercial items, full and open competition, selection of appropriate contract type, and appropriate consideration of the use of pre-existing contracts. FAR 7.105, *Contents of Written Acquisition Plans*.

[38] NASA OIG, *NASA's Management of the Orion Multi-Purpose Crew Vehicle Program* (IG-20-018, July 16, 2020).

CONCLUSION

NASA is developing the next-generation extravehicular spacesuits to support multiple programs: HLS, ISS, and Gateway. Since our 2017 report on NASA's management of spacesuit development efforts, the need for the new suit has only increased with the Agency's 2024 "boots on the Moon" goal and the continued deterioration of the aging suits currently in use on the ISS. However, a flight-ready suit remains years away from completion. NASA officials expect to spend over $1 billion on design, testing, qualification, and development efforts before two flight-ready suits are available for use. Further, the xEVA Project has encountered multiple challenges, including budget reductions, ongoing COVID-19 impacts, and technical problems. These issues have resulted in approximately 20 months of delay to the flight suit delivery schedule. Further, the full impact of the COVID-19 pandemic has yet to be realized, and additional technical issues will be uncovered as the suits enter the testing phase, exacerbated by concurrent development and testing.

Given these anticipated delays in spacesuit development, a lunar landing in late 2024 is not feasible. That said, NASA's inability to complete development of xEMUs for a 2024 Moon landing is by no means the only factor impacting the viability of the Agency's current return-to-the-Moon timetable. For example, our previous audit work identified significant delays in other major programs essential to a lunar landing, including the Space Launch System rocket and Orion capsule. Moreover, delays related to lunar lander development and the recently decided lander contract award bid protests will also preclude a 2024 landing.

The Agency will continue to manage significant risks as it develops suits to meet the performance and schedule needs of multiple programs in different phases of design and development. The lunar landing relies on the HLS Program, which is early in the design phase, but has specific requirements for the technical capability, functionality, and overall size of the suits. However, the suits are also needed as soon as possible by the ISS Program to replace aging suits that have exceeded their design life by more than 25 years, necessitating costly maintenance to ensure astronaut safety. Thus far, NASA has struggled to align these schedules with mission needs.

Finally, as NASA considers its acquisition strategy for acquiring extravehicular suits, officials need to ensure technical requirements for the xEVA System are further refined. As prior OIG audit work has shown, entering into a contract without firm requirements often results in increased costs and schedule growth. Given the importance of xEMUs for the ISS, a lunar landing, and other activities beyond low Earth orbit, failure to overcome these challenges will hinder NASA's ability to meet its human exploration goals.

Recommendations, Management's Response, and Our Evaluation

To ensure the successful development and implementation of the xEMU, we made the following recommendations to the Associate Administrator for the Human Exploration and Operations Mission Directorate:

1. To the extent that the schedule for Artemis III is extended beyond 2024, adjust the xEVA System schedule as appropriate to reduce development risks. For example, this could include
   a. ensuring at least the first two xEMU flight suits can also be used for ISS priorities,
   b. reducing the risk of concurrency in development of xEMU testing and qualification suits, and/or
   c. baselining the xEVA system schedule and ensuring the schedule incorporates margin and factors in the high likelihood of unrealized schedule risks.
2. Develop an integrated master schedule to incorporate and align the hardware deliveries and training needs of the dependent programs—Gateway, ISS, and HLS—and the Flight Operations Directorate.
3. Ensure technical requirements for the next-generation suits are solidified before selecting the acquisition strategy to procure suits for the ISS and Artemis programs.
4. Develop an acquisition strategy for the next-generation spacesuits that meets the needs of both the ISS and Artemis programs.

We provided a draft of this report to NASA management, who concurred with our four recommendations and described planned actions to address them. We consider management's comments responsive; therefore, the recommendations will be closed upon completion and verification of the proposed corrective 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; Susan Bachle, Project Manager; Thomas Dodd; Moriah Lee; and Sarah McGrath. Emily Bond provided editorial and graphic assistance. Earl Baker provided legal assistance.

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.

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Paul K. Martin
Inspector General

APPENDIX A: SCOPE AND METHODOLOGY

We performed this audit from August 2020 through July 2021 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.

Our overall objective was to examine NASA's development of next-generation spacesuits for Artemis missions and future deep space exploration. Specifically, we examined the extent to which NASA is addressing challenges related to cost, schedule, and performance of xEVA system development and production. To accomplish our objective, we performed work at Johnson Space Center and Marshall Space Flight Center.

To identify NASA spending on next-generation spacesuit development from FY 2008 through the first quarter of FY 2021, we reviewed and analyzed NASA's financial accounting system for total costs spent on the xEMU from the Constellation Program, Advanced Exploration Systems Division, the ISS Program, and the Gateway Program. We also reviewed planning, programming, budgeting, and execution information from the Gateway Program to determine future costs to be spent on the xEMU through FY 2026. Additionally, we interviewed officials with the Gateway Program's Planning and Control Office. To evaluate NASA's plans for completing development, including plans for the contract type and the timing of decisions being made, we reviewed Agency Requests for Information; presentations made to industry; the planned feasibility of, methodology for, and costs associated with the potential production and services contract; relevant laws and regulations, including Federal Acquisition Regulations such as FAR 7.102, *Policy*, and FAR 7.105, *Contents of Written Acquisition Plans*; and relevant Agency policies and procedures, including NASA Policy Directive (NPD) 1000.5C, *Policy for NASA Acquisition*. We also interviewed EVA Office management and contracting officials.

To understand the extent to which NASA is meeting schedule goals for the development of next-generation spacesuits, we reviewed and compared development and production schedule documentation provided by the EVA Office; Gateway, HLS, and ISS programs; and the Flight Operations Directorate. To determine if NASA's testing schedule for the xEMU provides enough time for sufficient testing of the spacesuit prior to the retirement of the ISS and before the spacesuits are needed for the Artemis III missions, we reviewed the xEVA strategic plan, industry workshop presentations, xEVA system life cycle schedules, and an Aerospace Safety Advisory Panel report. Additionally, we reviewed relevant Agency policies, guidance, and decision memorandums, including NASA Procedural Requirement (NPR) 7120.5E, *NASA's Space Flight Program and Project Management Requirements*; NASA Strategic Plan 2018; M2ME-DM-0001, *Moon to Mars Enterprise Decision Memorandum Surface Suits*; and M2ME-DM-0002, *Moon to Mars Enterprise Decision Memorandum Exploration Extra-Vehicular Activity and Gateway Logistics Services Resources and Management*. We also interviewed officials from the xEVA Project, EVA Office, Gateway, HLS, and ISS.

To assess the extent to which NASA is managing xEVA system and stakeholder program requirements and risks, we reviewed xEVA, Gateway, HLS, and ISS requirements documents; project risk tracking databases; and risk presentations to various risk and integration forums and boards, including the Joint EVA Data Integration forum and Gateway Risk Advisory Board. We also reviewed relevant NASA policies and procedures governing risk management, including NPR 8000.4B, *Agency Risk Management Procedural Requirements*, along with the xEMU, EVA, Gateway, HLS, and ISS risk management plans. We also interviewed xEVA Project, EVA Office, Gateway, HLS, and ISS officials.

Assessment of Data Reliability

Our audit used limited computer-processed data that we assessed as reliable. Primarily, we reviewed and analyzed NASA cost data from FY 2008 through December 2020 in NASA's financial accounting system for the Constellation Program, Advanced Exploration Systems Division, ISS Program, and the Gateway Program as it applied to the development of the xEMUs and VISE. We corroborated information with other sources where possible and performed audit steps to validate the accuracy of a limited amount of data contained in the databases. We determined that the data was sufficiently reliable for the purposes of this report.

Review of Internal Controls

We reviewed and evaluated the internal controls associated with NASA's development of next-generation spacesuits. We also reviewed appropriate policies, procedures, and regulations, and conducted interviews with responsible personnel. While we concluded that the internal controls were adequate, because our review was limited to these internal control components and underlying principles, it may not have disclosed all internal control deficiencies that may have existed at the time of this audit.

Prior Coverage

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

NASA Office of Inspector General

Artemis Status Update (IG-21-018, April 19, 2021)

NASA's Management of the Gateway Program for Artemis Missions (IG-21-004, November 10, 2020)

NASA's Management of the Orion Multi-Purpose Crew Vehicle Program (IG-20-018, July 16, 2020)

NASA's Management and Utilization of the International Space Program (IG-18-021, July 30, 2018)

NASA's Management and Development of Spacesuits (IG-17-018, April 26, 2017)

NASA's Plans for Human Exploration Beyond Low Earth Orbit (IG-17-017, April 13, 2017)

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

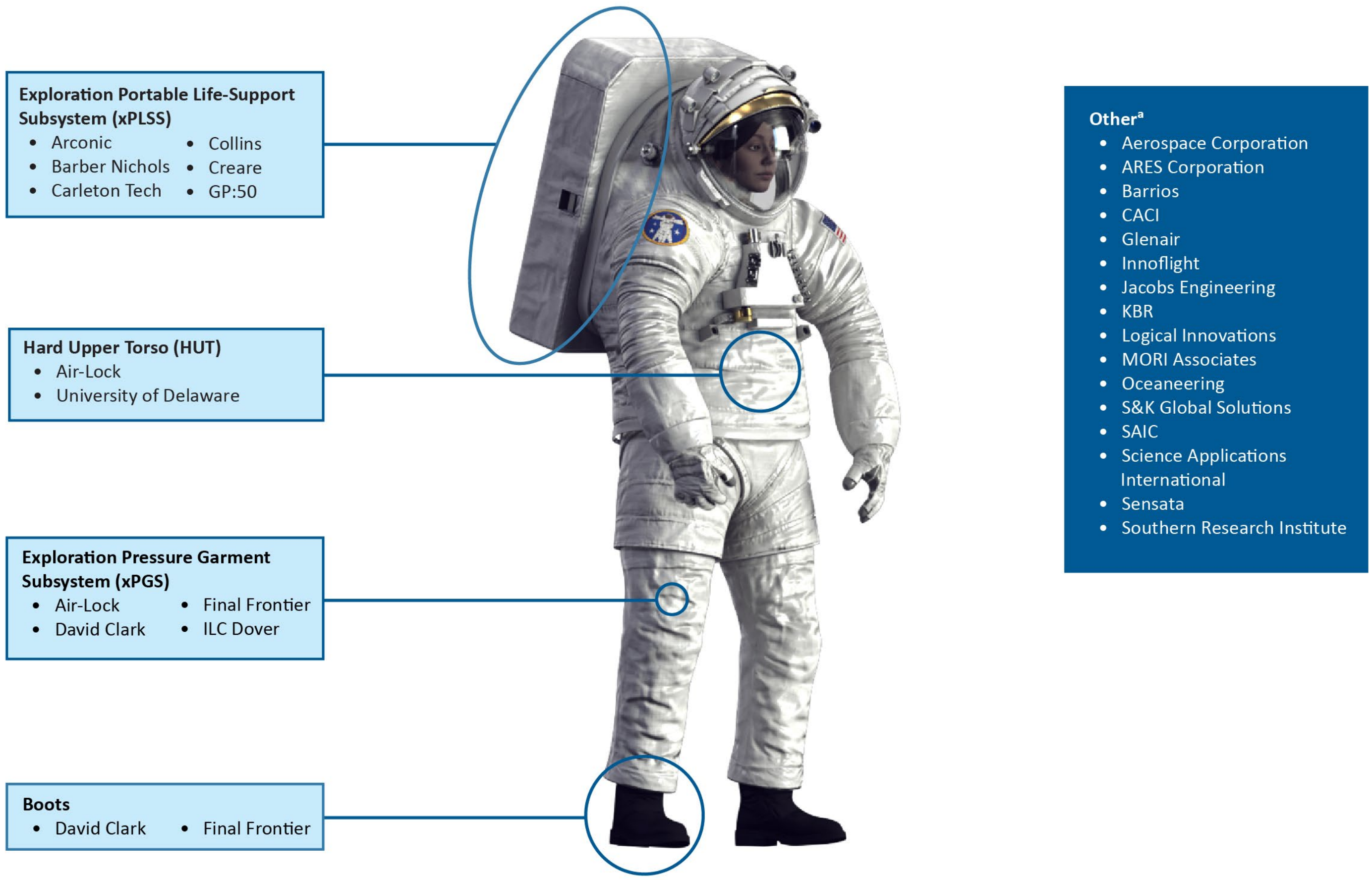
Government Accountability Office

NASA Lunar Programs: Opportunities Exist to Strengthen Analyses and Plans for Moon Landing (GAO-20-68, December 19, 2019)

Appendix B: Contractors and Vendors Providing xEMU Components

For the first six xEMUs, NASA planned to serve as the prime integrator, assembling the spacesuit from components supplied by 27 different contractors and vendors. Major components of the spacesuit include the xPLSS, Hard Upper Torso, xPGS, and boots. In total, there are 92 distinct end items that make up the xEMU. As shown in Figure 9, some of the vendors are involved in the design and development of multiple components. For example, Final Frontier and David Clark are both working on the xPGS and boots.

Figure 9: Contractors and Vendors by xEMU Component



Source: NASA OIG summary of NASA information.

[a] Other includes, for example, elements for communication, testing, and software.

APPENDIX C: MANAGEMENT'S COMMENTS

National Aeronautics and
Space Administration

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

August 4, 2021

Human Exploration and Operations Mission Directorate

TO: Assistant Inspector General for Audits

FROM: Associate Administrator for Human Exploration and Operations

SUBJECT: Agency Response to OIG Draft Report, "NASA's Management of Next Generation Spacesuits" (A-20-015-00)

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to review and comment on the Office of Inspector General (OIG) draft report entitled, "NASA's Management of Next-Generation Spacesuits" (A-20-015-00), dated July 6, 2021.

In the draft report, the OIG makes four recommendations to the Associate Administrator for the Human Exploration and Operations Mission Directorate to ensure the successful development and implementation of the Exploration Extravehicular Mobility Units (xEMUs).

Specifically, the OIG recommends the following:

Recommendation 1: To the extent that the schedule for Artemis III is extended beyond 2024, adjust the Exploration Extravehicular Activity (xEVA) System schedule as appropriate to reduce development risks. For example, this could include:

a. ensuring at least the first two xEMU flight suits can also be used for ISS priorities,
b. reducing the risk of concurrency in development of xEMU testing and qualification suits, and/or
c. baselining the xEVA system schedule and ensuring the schedule incorporates margin and factors in the high likelihood of unrealized schedule risks.

Management's Response: NASA concurs with the intent of this recommendation and intends to rebaseline the xEVA schedule. This new baseline will take into account the recent formulation and approval of the Exploration Extravehicular Activity Services (xEVAS) acquisition strategy, latest budget allocations for xEVA systems project, as well as revised Agency expectation for the International Space Station (ISS) EMU transition and first crewed Artemis mission. Demonstration and testing of the xEMU system on ISS are a priority. NASA intends to perform a demonstration prior to the first Artemis crewed mission. NASA will work with our eventual xEVA commercial supplier(s) to ensure adequate development milestones are in place and a balanced risk approach is taken to qualify and deliver xEVA flight systems for ISS and Artemis.

Estimated Completion Date: June 2022.

Recommendation 2: Develop an integrated master schedule to incorporate and align the hardware deliveries and training needs of the dependent programs—Gateway, ISS, and Human Landing System (HLS)—and the Flight Operations Directorate.

Management's Response: NASA concurs with the intent of this recommendation. The xEVA Project has maintained an Integrated Master Schedule (IMS) for all aspects of xEVA development since project inception in 2019. As Program (ISS, Gateway, and HLS) need dates mature, the xEVA Project will update the IMS to reflect the details of the schedule interdependencies as it relates to hardware delivery and EVA training needs. Initial training dates are reflected in the current xEVA system IMS. However, as flight dates mature and crew selections are determined, these training interdependencies will likewise be refined and updated. Similarly, as soon as NASA can continue discussions with awardee(s) of initial Artemis lander systems (Appendix H, Option A Broad Agency Announcement), a more comprehensive section in the IMS will be created to capture the specific interdependencies between xEVA and HLS lander development. Finally, an IMS will be a contract deliverable from xEVA's commercial provider(s), with initial submissions due as a part of proposals.

Estimated Completion Date: June 2022.

Recommendation 3: Ensure technical requirements for the next-generation suits are solidified before selecting the acquisition strategy to procure suits for the ISS and Artemis programs.

Management's Response: NASA concurs with the intent of this recommendation and will ensure that technical requirements for the next-generation suit are solidified before the Request for Proposal release to industry. NASA has created a strong foundation of system-level requirements and interface definition documents. The foundational document, the xEVA Suit Systems Requirements (SSP51073), has been baselined and approved by the ISS and Artemis Programs. This and several of the other baselined system level documents were created specifically to support an eventual industry transition. As such, the Requirements Development Team for the xEVAS procurement has utilized this library of requirements and intends to make many of these documents directly applicable on the contract. NASA will continue to manage and update as required all program interface requirements and documents to ensure proper integration with ISS and Artemis elements.

Estimated Completion Date: October 2021.

Recommendation 4: Develop an acquisition strategy for the next-generation spacesuits that meets the needs of both the ISS and Artemis programs.

Management's Response: NASA concurs with this recommendation, and the xEVAS acquisition strategy includes requirements to assure that the needs of both the ISS and Artemis programs will be met, while also allowing maximum contract flexibility for future unknown program and/or mission needs.

Estimated Completion Date: October 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 Kelly O'Rourke on (202) 358-1635.

KATHRYN LUEDERS

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Kathryn L. Lueders

APPENDIX D: REPORT DISTRIBUTION

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

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House Committee on Appropriations
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House Committee on Oversight and Government Reform
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(Assignment No. A-20-015-00)