NASA Advanced Space Suit Pressure Garment System Status and Development Priorities 2023

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This paper discusses the current focus of NASA's Advanced Space Suit Pressure Garment Technology Development team's efforts, the status of that work, and a summary of longer term technology development priorities and activities. The Exploration Extra-vehicular Activity Mobility Unit (xEMU) has been the team's primary effort over the past several years. ICES papers in 2022 detailed the design of the xEMU pressure garment components. This paper outlines the design updates to the xPGS since that time. More notably, this paper documents the various tests executed with the xPGS to evaluate its performance, durability, and acceptability for microgravity and Lunar missions. An overview of ongoing and planned xEMU testing and training is provided. The PGS team's transition from xEMU development and testing, to supporting the Exploration Extravehicular Activity Services (xEVAS) vendors is discussed. In addition, technology development efforts in coordination with the EVA and Human Surface Mobility Program (EHP), the NASA Engineering Safety Council (NESC) and the Small Business Innovation Research (SBIR) Program will be discussed in the context of supporting sustaining EVA operations on the Lunar surface over the coming decade. Finally, a brief review of longer-term pressure garment challenges and technology gaps will be presented to provide an understanding of the advanced pressure garment team's technology investment priorities and needs.

Nomenclature

ARGOS	=	*Active Response Gravity Offload System*
CO_2	=	*carbon dioxide*
DVT	=	*Design Verification Testing*
EHP	=	*EVA and Human Mobility Program*
EMU	=	*Extra-Vehicular Mobility Unit*
EPG	=	*Environmental Protection Garment*
EVA	=	*Extra-Vehicular Activity*
EVVA	=	*Extra-Vehicular Visor Assembly*
GFE	=	*Government-Furnished Equipment*
HLS	=	*Human Landing System*
HUT	=	*Hard Upper Torso*
ISS	=	*International Space Station*
LCVG	=	*Liquid Cooling and Ventilation Garment*

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LEVA = *Lunar Extravehicular Visor Assembly*
LTV = *Lunar Terrain Vehicle*
NASA = *National Aeronautics and Space Administration*
NBL = *Neutral Buoyancy Laboratory*
NESC = *NASA Engineering Safety Council*
PGS = *Pressure Garment Subsystem*
PLSS = *Portable Life Support System*
PSR = *Permanently Shadowed Region*
PTRS = *Project Technical Requirements Specification*
RFI = *Request for Information*
RFP = *Request for Proposal*
SBIR = *Small Business Innovative Research*
SHERLOC = *Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals*
SxEMU = *Short Exploration Extra-Vehicular Mobility Unit*
STTR = *Small Business Technology Transfer*
TVAC = *Thermal Vacuum Chamber*
xEMU = *Exploration Extra-Vehicular Mobility Unit*
xEVAS = *Exploration Extra-Vehicular Activity Services (contract)*
xINFO = *Exploration Informatics Sub-system*
xPGS = *Exploration Pressure Garment Sub-system*

I. Introduction

ARTEMIS III, the NASA mission to land humans on the surface of the Moon for the first time in more than 50 years, is currently scheduled for 2025. In addition, the dwindling fleet of EMU hardware to support International Space Station (ISS) EVAs has continued to cause logistical challenges. New suits are under development to support both of these capabilities. The Advanced Space Suit Pressure Garment Technology Development team ("Advanced Suit Team") at NASA's Johnson Space Center continues to work to this mission, supporting the NASA mission as it relates to EVA. The Exploration Extra-Vehicular Mobility Unit, or xEMU, has been the primary focus of the Advanced Suit Team for the past several years. Delivery of multiple full xEMU pressure garment (xPGS) assemblies and Design Verification Testing (DVT) were completed in the summer of 2022. Multiple publications have recently documented the xPGS assembly[1] and components[2,3,4,5,6,7,8,9,10] design, as well as preliminary results from DVT[1]. Subsequently, mobility and cycle testing campaigns were completed in reduced gravity using the Active Response Gravity Offload System (ARGOS) at Johnson Space Center (JSC). Training runs at the Neutral Buoyancy Laboratory (NBL) and other evaluations have also provided significant meaningful information about the xEMU suit's performance.

Meanwhile, the team has transitioned to supporting the eXploration Extra-Vehicular Activity Services (xEVAS) contract and the two contracting partners, Collins Aerospace and Axiom Space. Lastly, we have focused technology development efforts on sustaining Lunar operations and the specific challenges of those missions.

This paper highlights all these ongoing technical efforts in support of both Artemis and International Space Station (ISS) programs.

II. Team Mission

Over the past five years, the Advanced Suit Team at JSC has managed through a lot of change, from working a demonstration mission of the xEMU at the ISS, to initiation of a Government-Furnished Equipment (GFE) effort for the Artemis Program suit, to transition of Artemis suits to a commercial services contract. With the xEVAS contract now underway with awarded task orders and a firmer outlook of the Artemis program in general, it is prudent to orient the reader to the mission and strategy that the team is employing to best support that mission.

The NASA Advanced Suit Team's mission is to cultivate the development of spacesuit assemblies and technologies that will enable NASA to meet its human exploration goals. A key part of this mission relies on the assessment and mitigation of suit-related risks to NASA missions. These risks include both short term, specific to a single EVA, and long term, beyond not just the current program but beyond the next one as well. This work includes mitigation of very specific risks, but also applies more broadly, such as system level testing, integration, and technology development efforts. In that context and in retrospect, the xEMU project squares firmly with that mission in that it matured a new suit platform that serves as a government reference design to enable program integration and planning and to help position the xEVAS vendors for success.

III. xPGS

The xEMU project evolved over time. In 2019, the xEMU Demo pressure garment architecture was presented[11], which included a new HUT, Shoulders, Helmet, and Extra-Vehicular Visor Assembly (EVVA), while reusing the EMU lower torso, arms, gloves, and boots. The xEMU Demo project covered the manufacturing of a single PLSS and Pressure Garment Subsystem (PGS) and a single flight demonstration on the ISS. The project's intent was to conduct a flight demonstration of new technologies and then transition fleet manufacturing and sustaining to a prime contractor to replace the EMU. However, with the new direction in 2019 to put boots on the moon by 2024, the xEMU project was identified as the best path to manufacture suits for the initial lunar mission, projected to occur near the lunar south pole. As a result, the xEMU project transitioned into a multiple program flight project, that included development of both a suit for the ISS and for the first Artemis lunar surface mission. This transition to a multi-program, multi-destination system was a significant change in project scope and requirements which resulted in changes to the xEMU's architecture. These changes included improved lower torso mobility, Lunar boots that meet challenging thermal requirements of the permanently shadowed regions (PSR) of the Moon, a new environmental protection garment (EPG) for dust protection, and enhanced cycle life performance over the needs of the ISS. The xPGS DVT unit, the pressure garment of the xEMU is shown at right in Figure 1. For much more detail on the design of the xPGS and the components that comprise it, the reader will refer to the various manuscripts published in 2022 [1,2,3,4,5,6,7,8,9,10].

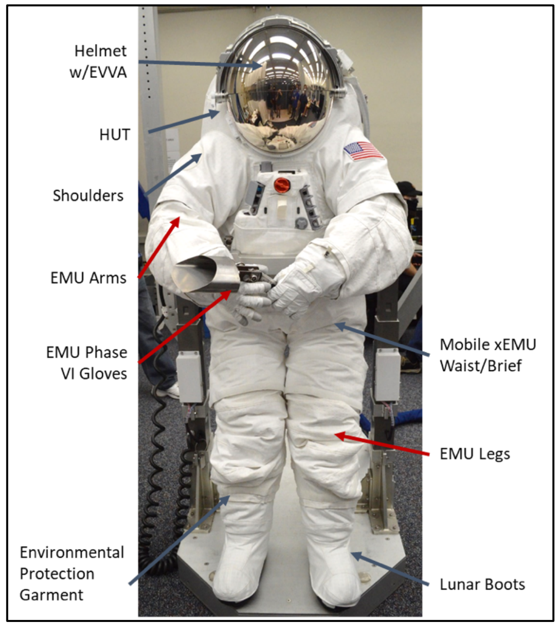

Figure 1: xPGS Design Overview

A. xEMU Design Verification Testing (DVT)

One of the lessons conveyed from Gemini, Apollo, and EMU suit programs was the importance in building and testing a development unit before attempting suit certification. The xEMU project therefore was conceived including a development unit which would be evaluated in Design Verification Testing (DVT). DVT is an opportunity to take the prototype hardware through select certification-like tests to reduce risk that the design will pass certification. Some of the highest priority subsystem tests focused on evaluation by multiple subjects from across the anthropometric range against requirements for mobility, fit and comfort, and cycle life. For the xPGS team, DVT was comprised of Mobility testing, Cycle (Life) testing, and functional testing of the water and air loop, as well as myriad PGS component-level tests.

Mobility testing was executed in both 1G and 1/6G using ARGOS and was completed in May 2022. The test was composed of test subjects from seven different sizing clusters, completing a battery of tasks that represent the expected mobility needed for planetary EVAs. Subjective and objective metrics for mobility, fit and comfort were collected. Cumulatively, the lessons learned from DVT Mobility are below. The high-level lessons learned from mobility testing as listed below. More detail on mobility testing is available in another report, ICES-2023-257, Mobility Test for xPGS[12].

- The xPGS suit was able to satisfactorily provide the mobility to complete all necessary tasks across the entire subject pool.
- A desired change to the EPG architecture was identified and implemented due to mobility restrictions induced by the full EPG ply combined with the coverage required for dust protection.

- For planetary tasks such as kneeling to pick up an object, the ARGOS platform induces a significant effect on simulation quality as it relates to mobility, stability, and reach.
- Mobility testing provided meaningful data about xPGS performance, and valuable experience utilizing the xPGS hardware, ARGOS test environment, and test protocol that was carried into DVT cycle life testing.

Cycle life testing of the xPGS was executed in 1/6G using ARGOS and was completed in September 2022. The test was composed of nine subjects completing a series of 9 functional task circuits. Each circuit was completed a number of times that correlated to twice the total number of joint and mechanism cycles as would be expected in the Artemis mission. More detail on the specifics of the xEMU cycle model and the results of the cycle testing are available in ICES-2023-058, Cycle Test for xPGS[22]. For the purposes of a high-level summary, DVT Cycling lessons learned are as follows:

- The xPGS was able to complete all necessary cycles and demonstrated general acceptability for initial Lunar missions. Areas of wear were identified for further evaluation and mitigation.
- Glove cycling wasn't intended to be part of the cycle test, however the significant wear seen during testing, as well as analysis of the design and environment show that existing EMU glove designs are inadequate in meeting demands of Lunar cycling.
- The water and vent loop connectors that connect to the Liquid Cooling and Ventilation Garment (LCVG) cause persistent wear issues when combined with a walking lower torso, and the rolling convolute waist in particular.
- All xPGS components received some wear or damage which was documented, and in many cases, mitigated.
- Cycle testing provided meaningful data on xPGS cycle life performance which has been made available to the xEVAS vendor partners.

NBL and other post-DVT testing is currently underway by the PGS integrated test support team to aid in evaluation of training facilities, ISS, NASA's Human Landing System (HLS) and Lunar Terrain Vehicle (LTV), and other vehicle and human surface mobility asset interfaces. Evaluations include objectives to better define requirements, develop training facility infrastructure, dry-run training plans, and continue to evaluate the use of xEVA tools/support hardware. These test events are not specifically intended to evaluate the performance of the space suit. Utilization of the xPGS government reference design enables the team to continue to work through integration and preparation plans while the suits are being developed under xEVAS. It is with these objectives in mind that a series of 10 NBL tests were conducted in which the suit was weighed out to a simulated 1/6G, in the fall of 2022. Summary of the initial NBL test series lessons learned can be found in ICES-2023-034[14], and are summarized as follows:

- The NBL has the potential to provide a unique environment with realistically weighted mock-ups and tools for the lunar surface.
- A repeatable and functional weigh-out was not able to be achieved in previous testing. Incorporating sufficient weight to induce a realistically distributed 1/6g like ground reaction force under water without significantly compromising mobility is a challenge.
- Buoyancy and weight distributions, if not aligned well, can induct joint moments and significant test subject instability.
- Modifications to the NBL cover layer to transform it into a purpose-built weigh-out system, appears to be the best path forward.
- Water drag creates a persistent simulation quality effect on any dynamic movements.

B. xPGS Hardware Updates for FY23

Subsequent to the most recent xPGS overview published in 2022, there have been several updates and modifications to xPGS hardware.

Most notably, the Lunar boot received a major expected update that added EPG interfaces, dust proofing, boot tightening using a boa lacing system, and other refinements toward a more flight-like design. Due to the low state of maturity for the Lunar boots, which must survive permanently shadowed region (PSR) temperatures as low as -370°F [-223°C], the original procurement strategy was devised as a two-stage effort with an initial delivery and assessment in early DVT, and feedback to the vendors with a design iteration to increase maturity in late DVT. The updated boots from each vendor are shown below without an EPG in Figure 2.

Figure 2: Phase II David Clark (left) and Final Frontier Design (now Paragon, right) xPGS Boots

C. Follow on xPGS/xEMU Testing in FY23

Subsequent testing of xPGS and xEMU has been funded for FY23 which includes continued ambient testing of the short xEMU (xEMU without a lower torso for testing purposes only, also called SxEMU)_and Thermal Vacuum Chamber (TVAC) testing. The ambient testing's primary objective is to evaluate the performance of the xPLSS.

The TVAC Chamber B testing consists of two separate test articles; the SxEMU which will be primarily collecting xPLSS data and a separate xPGS Suit which will provide data on xPGS. TVAC article objectives are intended to provide further information on the government reference design to xEVAS vendors, in addition to being a pathfinder to demonstrate JSC chamber readiness to support any vendor desired testing.

The xPGS test article objectives for the TVAC include determining full suit system heat leak, verification of internal touch temperatures, thermal model validation of the DVT PGS thermal modeling, thermal performance of exterior hardware and to obtain boot thermal data with the Phase II xPGS boots. Secondary objectives of this test are to obtain a level of confidence in the xPGS hardware for potential future use in Human in the loop chamber testing, and to obtain additional audio data for xPLSS echo cancellation software.

In addition, the xPGS has supported supplemental testing at ARGOS and other facilities after completion of mobility and cycle testing. It is expected that the xPGS and xEMU will continue to support testing as determined by NASA to further characterize performance and to continue to support other programs or projects currently in work and in the future.

D. xPGS Lessons Learned

As of this publication, the xEMU is by far the highest maturity EVA suit development since the Enhanced EMU. In addition, considering the xPLSS, xPGS, ISS and Lunar configurations, tools, and xINFO, the xEMU is the most comprehensive suit development ever undertaken. Currently, the xPGS team is supporting multiple test series with the xPGS suits, including additional 1/6G NBL testing and the thermal vacuum chamber testing. Throughout DVT, post-DVT NBL testing, and other testing, the team continues to gain experience with the xPGS hardware. We continue to document these lessons for posterity and to share with the xEVAS vendor partners, who to a large extent are leveraging the xEMU designs in their architecture.

E. Existing Risks and Risk Mitigation Plans

The xPGS government reference design verification testing was successfully conducted and resulted in significant lessons learned. At this time, NASA is not systematically continuing to develop the xPGS towards flight, but instead utilizing it as a test bed for further development and integration evaluations. With that in mind, NASA is still assessing overall space suit risks and using xPGS suit as a testbed to mitigate the risks, provide risk mitigation options to xEVAS vendors, and reduce NASAs overall risk posture. The following are current risks that are being evaluated for possible risk mitigation:

Lunar suit durability

- Cycle life at elevated pressures

NASA has been developing elevated pressure suits, to enable zero pre-breathe since the 1970s. As NASA moves to more frequent EVAs, use of either elevated pressure suits and/or higher oxygen concentration habitats are expected. There is limited data on the expected life reduction of the space suit when operated at 8.2 psia instead of the current EVA pressure of 4.3 psia.

The PGS team has proposed repeating a subset of the cycle testing that was recently completed at 8.2 psia, to have a recent and direct comparison of cycle life at the two pressures.

- Suit durability in dust and PSR thermal extremes

The current state of the art Phase VI gloves were not developed for use on the lunar surface and there are very serious concerns about life in a dusty environment and the thermal performance in the demanding PSR temperatures. While much of the xEMU was designed for the Lunar surface, there are still unknowns about how the suit will perform with dust and in thermal extremes. For example, the boot outsole will be exposed to high loads and impact events on the Moon, while operating at temperatures as low as 50K.

The PGS team has been working with the NESC to establish standardized test methods to evaluate the performance of the glove on the lunar surface. In addition to that, the PGS team has proposed to evaluate alternate Environmental Protection Garment (EPG) designs that may address the existing risks.

Thermal model validation

- LCVG

The xEMU LCVG was designed to include additional tubing, compared to the current EMU flight design. The intent was to enable higher average and peak metabolic rates that are expected on planetary EVAs. Additionally, the xEMU LCVG has an auxiliary cooling loop that adds an additional 80 feet of cooling tubes for emergency cases. There is limited historical data comparing the cooling performance with added tubing length, or of the auxiliary cooling loop performance.

The xPGS team has proposed conducting those tests with the new LCVG design to validate the thermal model used to develop the current designs.

- Environment

EVAs at the lunar south pole will involve colder temperatures and different heat transfer methods, in comparison to LEO or previous lunar EVAs. NASAs current boot and EPG designs were driven based on thermal analysis models with limited test data to confirm the performance.

The boot design was developed to work for at least two hours in a PSR. Testing is required to validate the thermal model.

The EPG design was based off historical heat leak testing. Testing is required to validate that the historical heat leak values from EMU are consistent with other suit architectures.

Tribocharging and Shock

The ISS program manages a very specific shock and charging hazard induced by the ambient plasma environment and the vehicle architecture. This risk is mitigated by a combination of plasma contactor units on ISS structure, minor modifications to EMU hardware, and operational controls.

EVAs at the lunar south pole will be in a very different and dynamic plasma environment, combined with areas of permanent shade where charge can accumulate, as well as tribocharging between the lunar surface and the soles of the boots.

Testing, modeling, and development of mitigation strategies are required to address this risk.

Helmet Anti-Fog

The current EVA wipe-on anti-fog solution used on ISS has been suspected to cause eye discomfort during at least seven EMU EVAs. xEMU investigated HTAF-601 permanent anti-fog, but it had issues with durability and has been discontinued. Further testing has been completed on Exxene's HCF-100 and Visgard 106-94. Alternatively, there may be other approaches that do not require a coating or film. In response to this risk, NASA issued a solicitation on Small Business Innovative Research (SBIR) Phase I, with proposals currently under review as of May 2023.

Mars Suit Development

The xPGS was optimized for orbital or Lunar surface EVAs, with a mass consideration only in 1/6G and for overall system mass. However, EVAs on Mars will require new technologies and significant mass reductions from a Lunar suit. Composites and other non-metallics for structure, bearings and other components will require significant development and integration to a suit. The CO2 atmosphere of Mars calls for a completely different thermal management approach, so maturation of flexible aramid Aerogels or other high-performance thermal insulation materials is required. The unique dust environment coupled with minimal upmass and sparing will require the suits to be very durable and easy to maintain. The SHERLOC (Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals) experiment on the Mars Perseverance Rover is evaluating space suit materials and their degradation in the Mars radiation environment. A ground test unit is required to correlate this degradation to a real-world loss of material properties, so that NASA can better understand the risks of the Mars environment.

Electrochromic Visors

During Apollo, the Lunar Extravehicular Visor Assembly (LEVA) had reports of the mechanism becoming hard to operate due to dust. For long duration Artemis missions, this mechanical mechanism could prematurely fail, or the sun visors become unacceptably scratched as they are deployed and stowed. An electrochromic visor which can actively control tint could solve this issue. Work on this technology has been completed through SBIR Phase I and II, but additional maturation and integration to the suit must be completed.

LCVG Water and Vent Lines

During xPGS testing, the team observed suit component wear and discomfort which was caused by the water connectors at the front of the subject. The ganged water and vent line configuration work well in the EMU, with its minimal lower torso mobility and 0g environment. In the xPGS, the connectors migrated down into the lower torso, and was problematic in long-duration cycling of a planetary suit. There is renewed interest in pursuing a new vent and water loop routing scheme that is better optimized for the planetary suit architecture and missions.

CO2 Washout

Existing carbon dioxide (CO_2) washout models have not been completely correlated to test data, leaving a gap on understanding what the inspired CO_2 risks are during an EVA, as well as the test methods for certification of future suits.

IV. xEVAS

The EMU and Apollo suit developments were accomplished on large government contracts, initially competed and subsequently awarded to teams of private companies responsible for meeting the levied technical requirements, deliverables, and schedule on a cost-plus contract. These companies engineered, fabricated, assembled, tested, and certified the suit at the assembly level and then delivered that hardware to NASA. In contrast, the xEMU project was originally devised and thus far, executed as a government-furnished equipment (GFE) effort. NASA-led teams at JSC conducted much of the engineering and design, in tandem with myriad contractors and vendors on a component-level or part-level basis. The NASA-led teams were also responsible for assembly, testing, and certification. This means that the xEMU project is a significant departure from every previous EVA suit development. At the time, the capability of NASA in-house expertise as well as limited appetite for, and funds available to, award large contracts for EMU replacement and early Artemis architecture were significant factors in pursuing this GFE procurement strategy.

However, as the Artemis program matured and gained inertia, more funding became available as allocated from congress. The award of the Human Landing System (HLS), coupled with the recent successes in the Commercial Cargo and Crew programs, were catalysts for a change to xEMU procurement strategy. Over the summer of 2021, a Request for Information (RFI) and Request for Proposal (RFP) were posted to solicit responses by potential vendors or vendor teams to provide an ISS EMU suit replacement and the Artemis lunar suit as a service, wholly developed, certified, and owned by the vendor. Under this solicitation, called xEVAS (eXploration Extra-Vehicular Activity Services), NASA pays a fixed price for a vendor to provide an EVA service to support NASA missions in a similar way that Commercial Crew vendors provide a launch and ISS ferry service. The vendors are responsible for not only the suit design and fabrication but maintain ownership of the hardware itself; this also applies to EVA tools as well. This means the vendors will also be required to provide suit maintenance, logistics, sustaining engineering, etc. for their hardware; this historically fell under NASA's purview or were executed on post-delivery sustaining engineering contracts. Under the xEVAS contract, the complete xEMU reference design, NASA testing facilities, and NASA xEMU personnel have been made available for use by the vendor to leverage how they deem appropriate to meet technical and deliverable requirements.

In the summer of 2022 the government awarded the xEVAS contract to two vendors, Axiom Space and Collins Aerospace. The work under the contract is further authorized by the award of task orders. The xEVAS solicitation is written in a way that the government has the capability to add future additional vendors as it desires.

As of 2023, task orders have been awarded to two xEVAS industry partners. Axiom Space was awarded a task order in September 2022 to deliver the EVA system for the Artemis III mission. In December 2022, Collins Aerospace was awarded a task order to develop an EVA system for the International Space Station and complete a Critical Design Review in pursuit of that mission.

The Advanced Suit Team is currently supporting both task orders through support mechanisms identified in the xEVAS contract. The first support mechanism is called "Insight"; in this role, NASA personnel ensure that vendor development plans, designs and deliverables are consistent with contract requirements and will ensure NASA mission success. Due to providing Insight to both vendors and the high number of deliverables requiring review at one time, the advanced team currently has approximately four team members fulfilling the xEVAS Insight role in addition to other team responsibilities.

The second support mechanism is called "Collaboration". In this role, NASA personnel augment the xEVAS vendor teams to aid in development and hardware certification, as well as to gain detailed understanding of the hardware designs to facilitate additional support and identify future risk mitigation activities.

Due to the competitive procurement environment, NASA and NASA supporting contractors have implemented strict firewalls between team members as necessary. To ensure the success of the xEVAS procurement strategy, NASA recognizes the vital importance of protecting vendor information and intellectual property.

V. Current Technology Development Efforts

Underpinning the commercial services procurement strategy is the assumption that private companies are best positioned to provide human spaceflight architecture that also serves an emerging commercial market and a corresponding profit incentive outside of NASA. Implicit to this assumption is that in contrast, the government is best positioned to conduct longer-term research and development which does not currently have or may never have a profit incentive. Short term, the xPGS team is focused on supporting xEVAS.

Long term, the advanced suit team at JSC continues to look toward the future of suit development to be ready for what comes next. xEMU or xEVAS only gets us so far – a replacement of the EMU suit to support ISS missions through 2030, and initial Lunar EVA capability. Experience gained from using the initial Lunar suit may drive NASA to complete or oversee development to enhance performance or operations. Sustaining Lunar operations at a habitat may require significant improvements over the initial Lunar suit design – to provide longer-term durability, to facilitate interface with new lunar surface assets, and to improve operational efficiencies. Other exploration destinations of the future – Mars, Phobos/Deimos, or asteroids, may require different designs and materials.

With these goals in mind, below are the significant technology development efforts for the team as of FY23.

A. NASA Engineering Safety Council (NESC) glove risk mitigation

While the xEVAS vendor for Artemis is responsible to deliver Lunar gloves and to meet associated technical requirements, they have only been awarded one mission as of this writing. This does not necessarily drive them to meet longer-term durability requirements that would be associated with a sustaining presence at the South pole of the Moon. The NESC has coordinated and funded a project including advanced suit team personnel as well as representatives from other organizations across and outside of NASA to assist in risk mitigation of having acceptable gloves to support sustaining Lunar operations under the Artemis program.

This project started in June 2022 and is currently scheduled to be completed by December of 2023. It includes extensive material testing, dust testing, and thermal testing to address the specific challenge of Lunar PSRs. While results have not yet been reported and are still preliminary, this project will provide not only extensive knowledge around glove materials and design that will help address the risk going forward, but also standards which can be used to evaluate glove performance as well. More information on this project is published in ICES-2023-37[15].

B. EHP/DT Artemis Suit Material formulation

The Technology Development and Partnerships office (JSC Mailcode: DT) of the EVA and Human Mobility Program (EHP) has also recognized the risk associated with sustaining EVA operations on the Lunar surface as it pertains specifically to suit and glove environmental protection garments (EPG). In that context, EHP has funded the Advanced Suit Team with an initial formulation phase for the first quarter of FY23 to develop a project plan to fully address this risk over the coming several years. As of May 2023, this project has been funded for the remainder of FY23, with expectation for continued funding in FY24.

C. SBIR / STTR

Under the Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) programs at NASA, the advanced suit team is strategically pursuing technology development efforts that may enable risk mitigation and future NASA missions. As of this writing, these efforts include the following:

- EPG textile and material development
- Electrochromic visor materials
- Persistently antimicrobial suit bladder materials
- Advanced water connectors

As the agency continues to support sustaining operations at the ISS as well as the Artemis program, the advanced suit team will continue to cultivate an SBIR and STTR portfolio that addresses technology gaps posing programmatic risk to these missions.

VI. Conclusion

The advanced suit team at JSC continues to adapt to the changing landscape of exploration missions and commercial services. While it continues to be a dynamic time which will likely continue for many years to come, it is also a time for opportunity for those organizations that are able to adapt to that change. With that in mind, the Advanced Suit Team continues to position itself strategically to best leverage its extensive knowledge and expertise on pressure garment technologies. We look forward to what the next decade brings.

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