48th International Conference on Environmental Systems
8-12 July 2018, Albuquerque, New Mexico
ICES-2018-273

NASA's Advanced Extra-vehicular Activity Space Suit Pressure Garment 2018 Status and Development Plan

Amy Ross,[1] and Richard Rhodes [2]
NASA Johnson Space Center, Houston, TX, 77058

Shane McFarland[3]
NASA Johnson Space Center/MEI, Houston, TX, 77058

This paper presents both near-term and long-term NASA Advanced Extra-vehicular Activity (EVA) Pressure Garment development efforts. The near-term plan discusses the development of pressure garment components for the first design iteration of the International Space Station exploration space suit demonstration configuration, termed the xEMU Demo. The xEMU Demo effort is targeting a 2023-2025 flight demonstration timeframe. The Fiscal Year 2018 (FY18) tasks focus on either the initiation or maturation of component design, depending on the state of development of the components, and the assembly of a suit configuration, termed Z-2.5, that will be used to evaluate changes to the upper torso geometry in a Neutral Buoyancy Laboratory (NBL) test series. The geometry changes, which are being driven by the need to reduce the front-to-back dimension of the advanced extravehicular mobility unit, diverge from a proven shape, such as that of the Mark III Space Suit Technology Demonstrator. The 2018 efforts culminate in the Z-2.5 NBL test. The lessons learned from the Z-2.5 NBL test will inform the xEMU Demo design as the effort moves toward design verification testing and preliminary and critical design reviews. The long-term development plan looks to surface exploration and operations. Technology and knowledge gaps exist between the xEMU Demo configuration; a lunar surface capability, xEMU; and Mars surface suit, mEMU. The development plan takes into account both the priority and the anticipated development duration for each particular technology. The long-term development plan will be updated as risks are mitigated and gaps are closed, but its overarching structure will remain intact.

Nomenclature

AES = Advanced Exploration Systems
ALCVG = Auxiliary-loop Liquid Cooling and Ventilation Garment
ARGOS = Active Response Gravity Offload System
CDR = Critical Design Review
DVT = Design Verification Testing
ELTA = The Z-2 configuration using the ISS EMU Lower Torso Assembly
EMU = Extra-vehicular Mobility Unit
EPG = Environmental Protection Garment
EVA = Extra-vehicular Activity
EVVA = Extra-vehicular Visor Assembly
FY = Fiscal Year
HITL = Human-in-the-Loop
HUT = Hard Upper Torso
ICS = Integrated Communication System
ISS = International Space Station

---

[1] Lead for Advanced EVA Pressure Garment Development, Crew Survival and Space Suit System Branch, Mail Stop EC5.

[2] Space Suit Engineer, Crew Survival and Space Suit System Branch, Mail Stop EC5.

[3] Senior Project Engineer, Crew Survival and Space Suit System Branch, Mail Stop EC5.

LCVG = Liquid Cooling and Ventilation Garment
LTA = Lower Torso Assembly
MWC = Multiple Water Connector
mEMU = Mars EMU
NBL = Neutral Buoyancy Laboratory
PDR = Preliminary Design Review
PGS = Pressure Garment System
SAFER = Simplified Aid for EVA Rescue
SRR = System Requirements Review
SSAER = Space to Space Advanced EMU Radio
PLSS = Portable Life Support System
SBIR = Small Business Innovative Research
SHERLOC= Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals
STMD = Space Technology Mission Directorate
xEMU = Exploration EMU
xPGS = Exploration PGS
ZLTA = The Z-2 configuration using the Z-2 Lower Torso Assembly

I. Introduction

Over the past several decades, advanced space suit pressure garment development has progressed at widely varying paces: sometimes depending on small research grants with a skeleton crew, and other times working under a strong funding source with an expanded team. The number of space suit development efforts that have started and stopped are in the double digits, with the Constellation Program space suit effort being the most recently ended. Following the Constellation Program, a series of funding sources have pursued a program of hardware production versus investing in longer-lead technology research and development. The Z-2 advanced space suit prototype was the primary product of this effort to date.[1,2] The successes of the technology development effort and the need for new space suits led to funding from the International Space Station (ISS) Program for a demonstration of advanced space suit technology on ISS. This paper discusses the current plan for the ISS demonstration, as well as advanced pressure garment technology development that is relevant looking forward to the Lunar Orbiting Platform-Gateway and other future exploration missions.

II. Plan for ISS Demonstration of Space Suit Technology

The Advanced EVA team has been asked to support a demonstration of advanced space suit technology on ISS in the 2023-2025 timeframe.

The team is working to the following major milestones shown in Figure 1. Dates for intermediate milestones are missing because they are dependent upon the flight demonstration date and the project is studying both options, but a final determination has not yet been made.

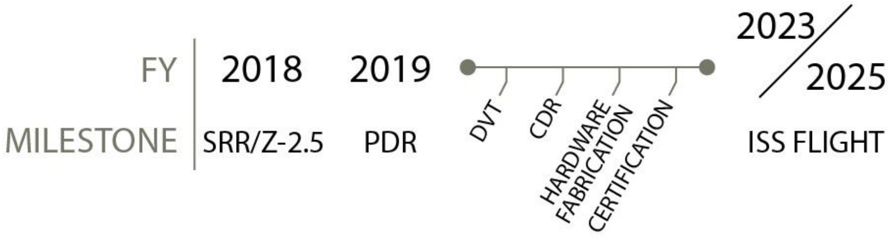

Figure 1: xEMU Demo Project Milestones

[Note: in this project DVT denotes an Engineering Unit evaluation vs. proto-certification testing]

The uncertainty regarding the timing of the ISS Flight demonstration arises from the difference between the original project deadline and an alternate deadline that is under consideration. When the project began, it was planned against a flight demonstration occurring in 2025. However, the ISS Program's official end currently is in

2024. Therefore, the project has been asked to provide a project plan that results in performing the flight demonstration in 2023, prior to the end of the ISS Program. The project is maintaining the schedule for the Preliminary Design Review (PDR) in 2019, but is determining the placement of subsequent milestones.

In order to meet this schedule, the Pressure Garment System (PGS) is building upon the work that was funded by the Advanced Exploration Systems (AES) Program that resulted in fabrication of the Z-2 advanced pressure garment prototype. The Z-2 is the culmination of over 20 years of planetary surface exploration pressure garment development and testing with its direct lineage tracing from the Mark III Advanced Space Suit Technology Demonstrator to the Waist-entry and Rear-entry I-Suits and, finally, the Z-1 prototype.[3,4,5,6] While these predecessors principally served as testbeds for planetary surface suit mobility joint system development, the Z-2 took steps to mature the hardware toward flight requirements and interfaces.[2] Two configurations of the Z-2 suit were used in a series of 19 Neutral Buoyancy Laboratory (NBL) tests to assess their ability to perform micro-gravity Extra-vehicular Activity (EVA) on the ISS.[1,7,8] The first configuration used the Z-2 mobile lower torso assembly (LTA) (ZLTA) in combination with its upper torso. The second configuration mated the Z-2 upper torso with an ISS Extra-vehicular Mobility Unit (EMU) lower torso (ELTA).

The architecture being proposed for the ISS Demonstration, labeled 'xEMU Demo' where the 'x' stands for 'Exploration', is similar to the ELTA configuration as shown in Figure 2.

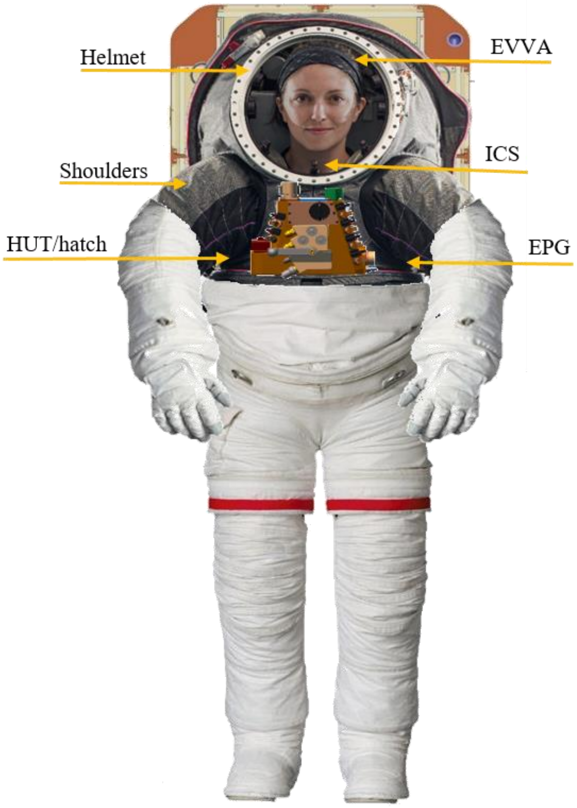

Figure 2: xEMU Demo FY18 PGS components

Therefore, the advanced PGS components of the xEMU Demo consist of the following:

- Hard Upper Torso, including hatch (HUT)
- Helmet
- Extra-vehicular Visor Assembly (EVVA)
- Shoulders
- Auxiliary-loop Liquid Cooling and Ventilation Garment (ALCVG)
- Integrated Communication System (ICS)
- Biomedical monitoring (termed Biomed)

- Dust mitigating Environmental Protection Garment (EPG) integration

The xEMU Demo efforts being performed in FY18 are driven by both changes recommended from the Z-2 NBL test series and preparation for PDR. The hardware revisions will be assembled into a prototype named Z-2.5, which will be used in a series of NBL tests at the end of year to provide confidence in the designs going into PDR. The effort for each component will be briefly described.

A. Hard Upper Torso

HUT work in FY18 focused on three areas: 1) changes to the HUT geometry, 2) composites development, and 3) a preliminary, HUT-focused fleet sizing study.

i. Geometry Changes

One of the major findings from the Z-2 NBL test was that the dimension from the front of the upper torso to the back edge of the Portable Life Support System (PLSS) was deep enough to make it more difficult to egress and ingress the ISS airlock hatch because careful alignment was needed.[7] Figure 3 illustrates the 5-inch (12.7-cm) difference between Z-2 and the ISS EMU system depths, without the Simplified Aid for EVA Rescue (SAFER). A major factor in this difference between the Z-2 and the ISS EMU is the angle of the hatch of the rear-entry Z-2 configuration.[1] The hatch is angled 9.5 degrees from vertical, whereas the EMU PLSS is oriented vertically. The rear-entry hatch angle results from connecting the waist bearing to the helmet ring, the orientations of which were selected to allow walking mobility and visibility, respectively. As can be seen in Figure 3, the depth difference is greater when the SAFER box is mounted at the bottom of the PLSS, extending the Z-2 system depth to approximately 30 inches. Figure 4 is an image from the NBL testing that demonstrates the limited clearances that results from the system depth when performing airlock ingress and egress. In Figure 4, the test subject is exiting the airlock in a heads-down attitude, with the subject's head pointed downward and their body oriented vertically.

Figure 3: Difference in system depths between Z-2 and ISS EMU

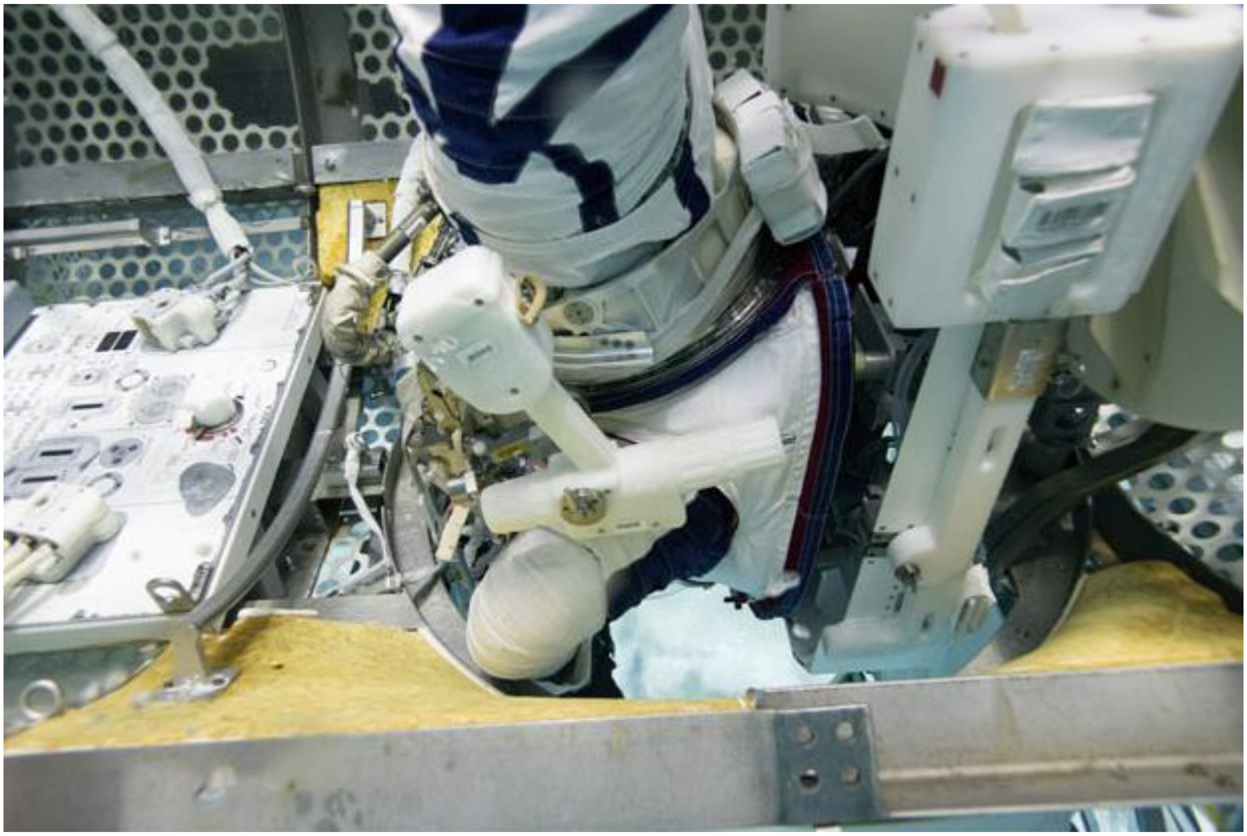

Figure 4: Limited clearances for airlock ingress/egress due to Z-2 system depth

In order to reduce the depth dimension, the PGS team changed the hatch and neck ring angles as shown in Figure 5. This represents a departure from heritage designs with hundreds of hours of suited test validation behind them. To mitigate the risk of the change in geometry, the team performed fit checks in a reconfigurable HUT rig and in a 3-dimension printed HUT. A design review was performed in March 2018 prior to Z-2.5 fabrication. The Z-2.5 HUT will be manufactured from aluminum as a means to achieve timely manufacture for testing this year, the xPGS Demo HUT will be constructed of S-glass. NBL tests of Z-2.5 will assess the effectiveness and acceptability of the changes.

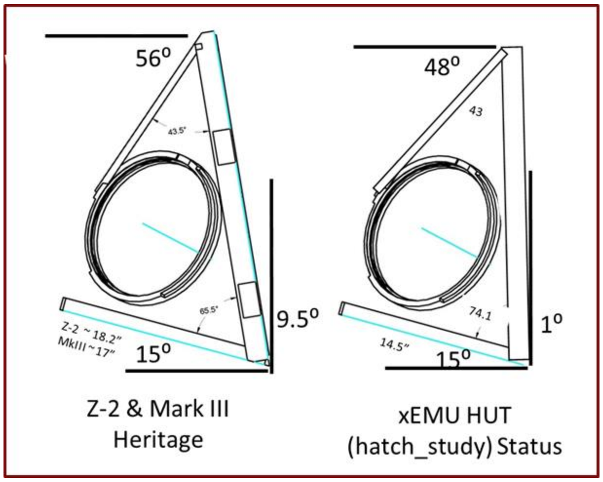

Figure 5: HUT geometry changes

ii. Composites Manufacturability

While the schedule has led to the decision to fabricate the xEMU Demo HUT from fiberglass (S-glass), the current intention for the xEMU is to fabricate it using an innovative, light-weight and durable material that has yet to be determined. A lesson learned from the Z-2 fabrication was that manufacturing techniques are as significant a challenge as material selection. This motivated an effort this year to execute a contract to study fabrication options, and then fabricate a HUT using streamlined composites manufacturing techniques. Results of the study will inform the xEMU Demo fabrication as well as that of the xEMU.

iii. Fleet Sizing

A preliminary fleet sizing study was performed to determine how many HUT sizes may be needed to accommodate the anthropometry range requirement for the xEMU. This is a preemptive measure to assess that the design of the xEMU Demo single size is scalable for full xEMU implementation at this early stage of development. As the exploration PGS (xPGS) system is being developed through the use of 3D modeling, the fleet sizing study utilized models of the upper torso components placed around a series of body scans from test subjects and crewmembers, and boundary manikins, which represent realistic combinations of body anthropometry across the sizing requirement. This technique enabled the team to conduct computer-based fit checks, validate the model results with 3D-printed prototype hardware, and then extend the modeling technique to the extreme boundary conditions of the population. This method allowed for quick evaluations of not only current crew population, but potential future crewmembers as well. Preliminary results indicate, with the 1-inch scye sizing feature in each HUT, that two HUT size may be able to accommodate the full population required.[1,2] Until the Z-2.5 fit checks and a large HUT is designed and fit checked, this result is not verified and carries the risk that additional sizes may be needed.

B. Helmet

Another finding from the Z-2 NBL test was that the helmet depth protruded to the extent that it interfered with the performance of tasks. There were several contributing factors, but a reduction in the helmet depth was identified as a means to help address the issue. The Z-2 helmet is an ellipse with a 13-inch major axis and 11-inch minor axis. For Z-2.5, the helmet minor axis is being reduced to 10 inches, which reduces the depth accordingly. Additionally, architectural changes are being made. The design concept for the EVVA that was generated on the Z-2 contract was for the EVVA to be sandwiched between the pressure bubble and the protective visor, making the protective visor the outermost layer. Moving forward for the xEMU Demo, the EVVA will be outermost with the protective visor next to the pressure bubble. This reduced the complexity required for the EVVA design and allowed for the depth of the system in the primary viewing area to be slightly smaller when the EVVA visors and shades are not deployed. Finally, a hard scratch resistance coating will be applied to the protective visor, but the other coatings, such as a hard anti-fog coating will not be included on this hardware. The hardcoat anti-fog was developed under the ISS EMU program, but has not yet been implemented on flight hardware. A Z-2.5 helmet, both pressure bubble and protective visor are being fabricated for evaluation in the NBL testing.

C. EVVA

For Z-2.5 the first xEMU Demo EVVA will be fabricated. Although new technology is anticipated for inclusion in the xEMU, for the xEMU Demo a traditional mechanical visor approach is necessary to meet the project schedule. Last year an EVVA concept was developed on contract. As discussed above, for the xEMU Demo, the EVVA is placed outboard of the helmet, which consists of the pressure bubble and protective visor. During Z-2 NBL testing softgoods EVVA mock-ups were used to determine the degree of occlusion from the EVVA that minimally impacted crew performance.[7] The NBL results balanced with a workable hardware approach led to the determination of an opaque visor section of no more than 60 degrees, maintaining at least 120 degrees of field of view, as shown in Figure 6. Additionally, the elliptical shape required a new approach in order to allow full coverage by the sun visor. The sun visor is divided into sections, as seen is Figure 6. During Z-2.5 NBL testing, this implementation will be evaluated along with visor operability. Although testing with the Z-2.5 will be the first iteration of EVVA evaluation, risk is reduced because of the design iteration planned prior to PDR that can address issues identified with the Z-2.5 EVVA configuration.

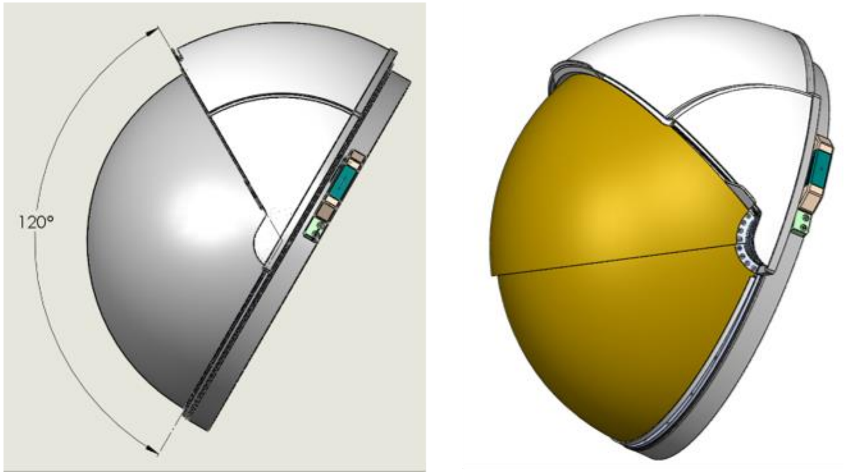

Figure 6: xEMU Demo EVVA Concept

D. Shoulders

In FY18, the goal for the shoulder is to mature the design to DVT fidelity. There are three areas being addressed to meet this goal: 1) Address Z-2 NBL feedback[7], 2) incorporate design features required for xEMU Demo, and 3) incorporate exploration forward design features.

The first shoulder design change to address Z-2 NBL feedback stems from the same ‘helmet depth’ issue discussed in the helmet section. As with most pressure garment issues, the ‘helmet depth’ issue is an integrated problem. A contributing factor to task interference experienced by some of the subjects was their position in the suit. For crewmembers with smaller chest dimensions, the scye is moved inward, which improves their fit, specifically placement of their shoulder with the shoulder joint mobility component of the suit. However the scye bearing intrudes into the inner volume of the suit such that the depth of the bearing affects how far forward in the suit the subject can be positioned. Reducing the scye bearing depth allows subjects to be positioned more forward in the suit which improves reach, thus limiting the impact of the helmet depth on work envelope.

Although the external link rolling convolute shoulder selected for the xEMU Demo is a heritage design, the shoulders used in prototype space suits have not incorporated safety features that are required for a flight pressure garment. The DVT shoulder design is incorporating redundant seals.

To improve flight operations, the secondary axial restraint brackets are also being modified. With the Z-2 design, the secondary brackets had to be removed in order to remove the shoulder from the HUT, but this is overly work intensive for on-orbit operations. A bracket modification being incorporated on the Z-2.5 shoulder design allows the shoulder to be removed without any disassembly.

Finally, features are being incorporated into the shoulder hardware designs to allow for integration of the EPG in a way that is envisioned to mitigate dust intrusion into the joint.

E. Auxiliary-loop LCVG

The exploration PLSS is building in redundancy to critical systems. As the case in point, the thermal system is comprised of a primary thermal loop and an auxiliary thermal loop, which are physically separate and functionally independent from each other. This physical isolation extends to the Liquid Cooling and Ventilation Garment, which includes additional water lines for the auxiliary thermal loop creating an Auxiliary-loop LCVG (ALCVG). To clarify, the auxiliary thermal loop is not fully functionally redundant, so the water line length in the ALCVG is of shorter length, and therefore reduced cooling capacity, from that of the primary loop.

Water line redundancy was explored during the Constellation Program and the Constellation Space Suit System produced two generations of ALCVGs. The first generation was utilized in a PLSS 2.0 Human-in-the-Loop test.[9] Note that in this report the ALCVG is termed a Redundant Loop LCVG. The second generation garments were modified to address fit and pressure garment integration findings from fit checks and the PLSS 2.0 HITL test. The team is planning to make additional modifications to the second generation CSSS ALCVGs for use in the Z-2.5 NBL tests. The modifications include removal of the CSSS ventilation system and installation of an EMU LCVG ventilation system. Fit checks will determine any other changes that must be made so that the garments can be used effectively in the Z-2.5 NBL testing.

In parallel, an effort to design the LCVG for the xEMU Demo and xEMU is underway. Water tube material, size, and placement; ventilation tube material, shape and placement; manifold designs; garment base material; and tube integration methods are all open to consideration. The architecture will remain a one-piece coverall. This year specific trades on water tube materials and shapes will be completed. The team also plans to begin design and fabrication of full garment prototypes that will be produced in time to support PDR and DVT. The remaining open trades will be addressed through this effort. Following fabrication the ALCVG will be subjected to a series of tests, including a thermal performance evaluation.

Another design change will be a change of material for the Multiple Water Connector (MWC). The PLSS water loop is being constructed of titanium, therefore, the connectors on the LCVG will be consistent with that choice so as to prevent galvanic corrosion of the thermal loop materials. The EMU multiple water connector will be fabricated from titanium and incorporated into the DVT ALCVG. The auxiliary connector will be based off a connector designed for the Orion Crew Survival Suit and also modified to titanium construction and incorporated.

F. Integrated Communication System (ICS)

During the Z-2 testing, overall feedback was favorable regarding use of an ICS, which is integrated into the HUT and not head-worn, versus the ISS EMU head-worn communication carrier assembly, but some specific comments regarding system performance are being addressed in the Z-2.5 design.[7] The team received comments that the sound quality sounded 'tinny.' New speakers are being selected to provide better sound quality. Alternate speaker locations to the neck placement are being evaluated to maximize the volume in the helmet. To provide better resistance to electromagnetic interference, new digital microphones are being selected. Audio feedback that may be created by side tone during ISS flight operations is being evaluated and addressed by a combination of architecture design and hardware solutions. Alternate speaker locations to the neck placement are being evaluated to maximize the volume in the helmet. Additional funds have been requested to perform radiation testing on ICS components in an effort to accelerate development.

An additional effort this year is to deliver a ground-based version of the Space to Space Advanced EMU Radio (SSAER). The SSAER will be the radio in xEMU Demo/xEMU that communicates with the ISS and, hence, with Mission Control. The ground-based unit of the SSAER serves two main functions; 1) It serves as a signal processor for the ICS and, 2) it interfaces the ICS with ground facility communication systems. The ground-based SSAER will also be used to evaluate some proposed features for the SSAER, such as audio compression and automatic gain control.

G. Biomedical Monitoring (Biomed)

The xPGS Demo is taking the opportunity to readdress the Biomed hardware design. The signal conditioner used on the ISS EMU is a circa 1975 design. Additionally, a result from the recent SRR was confirmation that for the xEMU, unlike the ISS EMU, the project is required to sense heart rate, not heart rhythm. Therefore, the team is undertaking a 'blank paper' design approach. The schedule for biomed hardware design is focused on meeting DVT and PDR, so will not be included in the Z-2.5 testing. There is a variety of off-the-shelf technologies that are used to collect heart rate data. These technologies are being reviewed. Selected technologies will be evaluated to determine a design solution for implementation. The technology will then be integrated into a space suit compatible design and fabricated for DVT.

H. Dust mitigating EPG integration

The Environmental Protection Garment (EPG) is the term for the outer pressure garment material layers that provide protection against thermal extremes and other damage from the outside environment. The EPG differs from the moniker 'Thermal Micrometeorite Garment (TMG)' used by the ISS EMU in that the EPG will also provide protection on a planetary body, where dust can be a significant hardware hazard to bearings, connectors, and soft goods.

To start, the team has been focused on dust mitigating EPG integration for the shoulder because it is the most complex component on the xEMU demo to address. Brainstorming and low-fidelity prototyping determined integration options to be studied via a higher-level prototype. Design changes to the shoulder hardware needed to accommodate the EPG integration designs are being coordinated with the shoulder component lead. Prototypes are in fabrication and testing with Z-2 is currently scheduled for April 2018 to downselect and finalize the EPG interface design. The team plans to evaluate the shoulder EPG design on Z-2.5, via collection of comments during fit checks and familiarization runs that are performed prior to NBL testing. As a baseline, this version will use the ISS EMU TMG material lay-up. A simple cover layer for Z-2.5 is being fabricated as a back-up plan. We have a goal to provide HUT and shoulder EPGs using an updated material lay-up that includes dust protection capability for the xEMU Demo.

In addition to the hardware efforts discussed, the Advanced PGS team continues to produce and mature significant documents toward PDR such as the PGS and component level specifications, a DVT and certification test plan, interface control decisions with the PLSS team, and an updated project budget.

FY19 will be focused on completing Z-2.5 NBL testing, DVT design, hardware fabrication and initiation of DVT testing. The Advanced PGS team will hold an internal design status review in preparation for PDR. The project's PDR is currently expected to occur early in the 3rd quarter of FY19.

III. Exploration EMU (xEMU) and Mars EMU (mEMU)

While the xEMU Demo focuses on hardware design maturation and certification for a near-term flight demonstration, it remains the Advanced PGS team's responsibility to lead technology development across the full technology readiness spectrum. Preparation for missions in the more distant future must continue so that the technologies and systems will be in place when they are needed.[10] In service to that duty, the Advanced PGS team is pursuing a variety of strategies and opportunities to identify and/or mature the technologies that are needed for different environments and more challenging missions. These sections discuss work the team is doing now on both the xEMU, for deep space and lunar surface operations, and the mEMU.

I. xEMU

The xEMU is envisioned to support the Gateway, including associated lunar surface EVAs, and Mars transit EVAs. Preliminary schedules place the need for a xEMU configuration, coming with the installation of an airlock onto the Gateway vehicle configuration, in the mid- to late-2020's. This would indicate that a xEMU effort should begin within the next few years and would run concurrently with the xEMU Demo effort for a period. As of this writing, an xEMU effort has yet to start; however, when feasible, a goal of the xEMU Demo project is to include as much exploration-forward technology and requirements as possible so as to minimize redesign efforts for the xEMU. The xEMU configuration is shown in Figure 7. As compared to Figure 2 the primary visual difference between the xEMU Demo is the replacement of the ISS EMU LTA with a mobile LTA.

Figure 7: xEMU Configuration

A less obvious difference between the configurations is the requirements gaps between the xEMU and those being applied to the xEMU Demo design and certification.[10] The Exploration EVA project is tracking those gaps with examples given in Table 1:

Table 1: Examples of xEMU Demo to xEMU Requirements Gaps

Requirement	**xEMU Demo**	**xEMU (with surface capability)**	**Notes:**
Operational Life/Cycles	100 hours/25 EVAs (100 hrs to be reviewed)	624 hours/156 EVAs	During xEMU Demo DVT, the PGS will be cycled past the xEMU Demo requirement to determine the scope of the gap.
Impact Protection	ISS EMU capability	Falls on the lunar surface	The xEMU Demo HUT will be constructed of fiberglass. The xEMU HUT material has not been selected yet.
Dust protection	Demonstrate dust resistant EPG interfaces; scar for dust resistant bearings, disconnects, and latches	Full protection	If schedule allows, xEMU Demo will attempt to incorporate new EPG lay-up. Latch and other mechanism designs are being reviewed for implementation of dust resistance features.
Self-don/doff capability	Scar design for mechanism	Capable	If resources allow, xEMU Demo will attempt to incorporate.
Environmental protection	Low Earth Orbit	Lunar surface	An approach to address secondary ejecta does not exist.

In the effort to close the gaps for xEMU, the Advanced PGS team has been utilizing a range of opportunities, which are described below.

Two new start proposals are being pursued in collaboration with the Deputy Environmental Control and Life Support System Capability Lead and Principal Technologist for the Space Technology Mission Directorate (STMD) to address impact protection, dust protection, environmental protection, and operational life gaps. For a potential FY19 start, a proposal was submitted for lightweight and robust materials development. This effort will identify and develop the new materials that are needed to meet stringent surface impact requirements while not increasing system mass and, potentially, resulting in a reduction in mass. It also will leverage the results from both completed Phase I and recently awarded Phase II Small Business Innovative Research (SBIR) grants that are developing innovative composite materials.

The second STMD proposal targets PGS softgoods to address operational life, dust protection, and environmental protection for the EPG. Submitted in March for a potential FY20 start, the efforts aims to achieve improved performance in ballistic impact protection (secondary ejecta) and optical properties to preserve thermal performance, radiation tolerance, and dust tolerance and mitigation. The team is eager to pursue non-traditional options including non-woven fabrics, polymer aerogel insulation, ultra-high molecular weight polyethylene, shear-thickening fluid infused fabric, liquid crystal polymer fabric, printed, and 3-D woven materials. This effort also leverages Phase I and Phase II SBIRs performed to develop materials that will improve EPG outer layer performance.[11,12]

For titanium bearings a Phase IIx SBIR proposal following the Phase I and Phase II SBIRs titled, “Contact Stress Design Parameters for Titanium Bearings,” was submitted to continue to address operational life and to incorporate dust protection and environmental protection.[13] Building on the improvements to operational life already attained in the SBIRs and on the design work made for the xEMU Demo, the proposal offers to further mature the bearings for xEMU implementation with inclusion of environmental seals and dust mitigating EPG interfaces.

The team is also proposing to implement an anti-shock coating system on metal components to provide passive, reliable, and low crew overhead plasma protection. Favorable results from Phase I and II SBIRs enabled this approach for environmental protection.[14]

As discussed above, cycle life data for the xEMU will be gathered during extended DVT and certification cycle testing. The data will inform xEMU design effort in that we will understand what systems will need designed to be more frequently and readily maintained. It also will inform a spares strategy.

Finally, in a less obvious approach to mitigating effects of the dust environment, the team is investigating electronic, versus mechanical, sun visors for the EVVA. A Phase I SBIR topic titled, ‘Controllable, Tinting, Polycarbonate Compatible Coating for Advanced EVA Spacesuit Visor’ had received six proposals for review at the time this paper was written.

J. mEMU

Mars may seem very far away, but the Advanced PGS team is taking steps toward the red planet.

A small but meaningful and symbolic step is through the Mars 2020 space suit exposure experiment.[15] The experiment is located on the calibration target for the Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC) instrument on the Mars 2020 rover. Figure 8 shows the location of the space suit material samples on the calibration target. The team has participated with the SHERLOC team through calibration target development and now is providing the materials for the flight hardware. Additionally, the team is curating the materials that will provide the ground truth data to compare with the data returned from the materials on Mars. The experiment allows the team to better understand when and to what degree space suit materials degrade in the radiation environment at the Martian surface. This allows the team to more accurately determine the durability, thus use life, of space suit softgoods over long-term use on Mars. To the best of the author’s knowledge, this will be the first time space suit materials reach Mars. Consider it the first very small step!

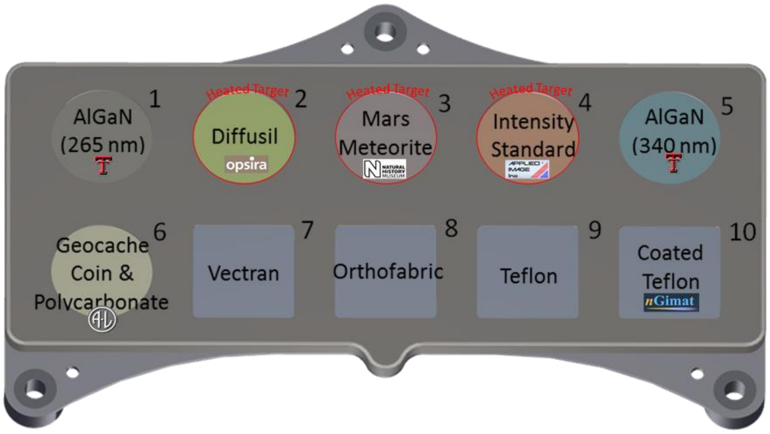

Figure 8: Mars 2020 SHERLOC Calibration Target with Space Suit Samples

During xEMU DVT testing, the Advanced PGS team will gather information regarding upper torso durability during suited cycle testing. The results will help guide a trade between designing for durability and a suit that can withstand the entire duration of a Mars mission, or designing to optimize sparing strategy. For both cases, the team will gather reliability data and determine the best approaches for long-duration mission suit maintenance. Additionally and applicable to both xEMU and mEMU, the team has requested funds through the xEMU Demo project to fabricate a mobile lower torso so that suited cycle testing can be performed. It is likely this testing would be performed on a treadmill using the Active Response Gravity Offload System (ARGOS). Funds also have been requested from the xEMU Demo project for integration of surface suit configurations with the ARGOS. These capabilities would allow mobility testing, including center of gravity impacts, in simulated lunar and Martian gravity. As any backpacker can attest, xEMU center of gravity is dictated in large by the PLSS packaging and center of gravity is one system-level characteristic that can drive the effort required to perform mobility tasks. The ARGOS provides a low-cost venue to perform mobility tasks to assess the combined performance obtained from the joint configurations, xPGS architecture, and system center of gravity. However, to assess truly assess the system mobility performance, eventually reduced gravity aircraft testing is necessary for the xEMU.

As the team works toward a lunar surface EPG, some of the work will be leveraged for the mEMU EPG.[16] For example, the team will generate material test strategies for a dusty environment that will likely be applicable to both xEMU and mEMU. Likewise, as materials are investigated for use in the lunar EPG, candidate materials for the mEMU EPG will be noted, as well. One area of the EPG that will be unique for Mars is the thermal insulation, as the mEMU and xEMU design solutions are likely mutually exclusive due to differences in thermal transfer modes between the locations. The team has identified this as a gap and is looking for ways to mature flexible aerogels or alternates for Mars.

Finally, the Advanced PGS team has been evolving our approach to capturing the PGS Technology Development Plan. We have determined that in order to be a valuable resource it needs to be published, at least within NASA, and updated annually. This drove a concise format from which proposal relevant data such as tasks, budget, and schedule could readily be mined. The team is in the process of populating the form by component for the three hardware iterations identified: xEMU Demo, xEMU, and mEMU. The goal is to better communicate our work and needs and to be better positioned to respond to funding opportunities. Next year’s status will provide an update on this effort.

IV. Conclusion

The Advanced PGS Team is striving to fulfill our role as the lead for the xEMU Demo PGS provider, as well as to nurture nascent and immature technologies that address needs for the pressure garments of the future. The team’s expertise in hardware maturation is quickly being deepened with the experiences from the xEMU Demo project. A structured approach for capturing the gaps between the xEMU Demo and xEMU has allowed for clear communication of needs, and has garnered support for addressing those gaps in preparation for the xEMU. The team optimizes funding received by endeavoring to gain knowledge for the mEMU effort, alongside pursuing funds for Mars-specific technology developments where they are needed.

Acknowledgments

The hard working Advanced PGS team has achieved remarkably, and I fully expect will continue to do so as they expect nothing less of themselves. The team will be ready for the next step(s) wherever our space suit boots will take us.

The management of the xEMU Demo project and Crew Survival and Space Suit Systems has been very supportive and active in that support.

The ISS Program and STMD have made this work possible with their foresight and funding support.

The SBIR program and the contractors who have performed work have allowed us to consider new possibilities and new solutions to old problems.

Thank you to all!

References

[1]Graziosi, D., et al. “Z-2 Architecture Description and Requirements Verification Results,” 46th International Conference on Environmental Systems, ICES, Inc. Vienna, Austria, July 2016. ICES-2016-301.

[2]Ross, Amy, et al. “Z-2 Prototype Space Suit Development,” 44th International Conference on Environmental Systems, ICES, Inc. Tucson, Arizona, July 2014. ICES-2014-091.

[3]Ross, Amy, Kosmo, J., Janoiko, B., Eppler, D. "Desert Research and Technology Studies 2004 Trip Report: EVA System Results." 35th ICES. SAE. July 2005, Rome, Italy: SAE, 2005.

[4]Ross, Amy, Kosmo, J., Janoiko, B., Bernard, C., Eppler, D., Splawn, K. "Desert Research and Technology Studies 2005 Report." 36th International Conference on Environmental Systems. Society of Automotive Engineers (SAE). July 2006, Norfolk, VA: SAE, 2006.

[5]Graziosi, David, Ferl, J., Splawn, K., Ross, A. "Evaluation of the Rear Entry I-Suit during Desert RATS Testing." 36th International Conference on Environmental Systems. Society of Automotive Engineers. July 2006, Norfolk, VA: SAE, 2006.

[6] Ross, Amy. 'Z-1 Prototype Space Suit Testing Summary." 43rd International Conference on Environmental Systems. American Institute of Aeronautics and Astronautics (AIAA). July 2013, Vail, CO: AIAA, 2013: NTRS JSC-CN-28415.

[7] Meginnis, I., Davis, K., and Rhodes, R. "Performance of Z-2 Space Suit in a Simulated Microgravity Environment," 48th International Conference on Environmental Systems, ICES, Inc. Albuquerque, New Mexico. July 2018. ICES-2017-71. (submitted for publication)

[8] Meginnis, I., Rhodes, R., Larson, K., and Ross, A., "Testing of the Z-2 Space Suit at the Neutral Buoyancy Laboratory," 47th International Conference on Environmental Systems, ICES, Inc. Charleston, South Carolina, July 2017. ICES-2017-250.

[9] Watts, C. and Vogel, M., "Space Suit Portable Life Support System 2.0 Human-in-the-Loop Testing," 46th International Conference on Environmental Systems, ICES, Inc. Vienna, Austria, July 2016. ICES-2016-87.

[10] Blanco, Raul and Lindsay Aitchison, "Methodology for Extravehicular Activity (EVA) Technology Identification, Prioritization, and Maturation," 48th International Conference on Environmental Systems, ICES, Inc. Albuquerque, New Mexico. July 2018. ICES-2017-54. (submitted for publication)

[11] Wettels, N., Marshall, P., Mahmoudzadeh, J., and Peters, B., "Polymer-Fabric Pressure Sensors for Space Suits," 48th International Conference on Environmental Systems, ICES, Inc. Albuquerque, New Mexico. July 2018. ICES-2017-65. (submitted for publication)

[12] Dombrowski, R., Wagner, N., Katzarova, M., and Peters, B., "Development of Advanced Environmental Protection Garments Containing Shear Thickening Fluid Enhanced Textiles (STF-Armor™) for Puncture Protection and Dust Mitigation," 48th International Conference on Environmental Systems, ICES, Inc. Albuquerque, New Mexico. July 2018. ICES-2017-183. (submitted for publication)

[13] Rhodes, R., Battisti, B., and Yuarte, R., "Development and Wear Evaluation of Titanium Spacesuit Bearings," 47th International Conference on Environmental Systems, ICES, Inc. Charleston, South Carolina, July 2017. ICES-2017-242.

[14] Runqing O., et al., "Shock Hazard Prevention through Self-Healing Insulative Coating on SSA Metallic Bearings," 47th International Conference on Environmental Systems, ICES, Inc. Charleston, South Carolina, July 2017. ICES-2017-363.

[15] Larson, K., and Fries, M., "Ultraviolet Testing of Space Suit Materials for Mars," 47th International Conference on Environmental Systems, ICES, Inc. Charleston, South Carolina, July 2016. ICES-2017-61.

[16] Ross, A., Aitchison, L., and Rhodes, R., "Advanced Extra-vehicular Activity Pressure Garment Requirements Development," 45th International Conference on Environmental Systems, ICES, Inc. Bellevue, Washington July 2015. ICES-2015-031.