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NASA Advanced Space Suit Pressure Garment System Status and Development Priorities 2019

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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 Unit (xEMU) project's International Space Station Demonstration Suit (xEMU Demo) project continues to be the team's primary customer and effort. In 2018 the team was engaged in addressing hardware design changes identified in the Z-2 pressure garment prototype Neutral Buoyancy Laboratory (NBL) test results. These changes will be discussed. Additionally components whose first iterations were produced in 2018 will be discussed. A full pressure garment prototype, termed Z-2.5, was assembled that is composed of updated and first prototype iteration hardware. Z-2.5 NBL testing, performed from October 2018 through April 2019 will inform final design iterations in preparation for the xEMU Demo preliminary design review planned to occur in the third quarter of government fiscal year 2019. A primary objective of the Z-2.5 NBL testing is to validate changes made to the hard upper torso geometry, which depart from the planetary walking suit upper torso geometry that has been used over the last 30 years. The team continues to work technology development, with GFY2018 work being used to supplement and feed the gaps left by the scope defined for the xEMU Demo. Specifically, a Phase IIx Small Business Innovative Research Grant to mature durable bearings that are compatible with a dust environment and a grant funded by the Science Technology Mission Directorate, Lightweight and Robust Exploration Space Suit (LARESS) project, to mature planetary impact requirements and hardware will be described. 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

ALCVG = Auxiliary-loop Liquid Cooling and Ventilation Garment
ARGOS = Active Response Gravity Offload System
CDR = Critical Design Review
COTS = Commercial-Off-the-Shelf
DCU = Display and Control Unit
DVT = Design Verification Testing
EMU = Extra-vehicular Mobility Unit
EPG = Environmental Protection Garment
EVA = Extra-vehicular Activity
EVVA = Extra-vehicular Visor Assembly

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FY = Fiscal Year
GSE = Ground Support Equipment
HUT = Hard Upper Torso
ICS = Integrated Communication System
ISS = International Space Station
LARESS = Light-weight and Robust Exploration Space Suit
LCVG = Liquid Cooling and Ventilation Garment
LTA = Lower Torso Assembly
MWC = Multiple Water Connector
NBL = Neutral Buoyancy Laboratory
PDR = Preliminary Design Review
PGS = Pressure Garment System
SSAER = Space-to-Space Advanced EMU Radio
SRR = System Requirements Review
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
WHRM = Wired Heart Rate Monitor
xEMU Demo = Exploration EMU Demonstration
xLCVG = Exploration Liquid Cooling and Ventilation Garment
xPGS = Exploration PGS

I. Introduction

AS discussed last year, the Advanced EVA team is working to demonstrate advanced space suit technologies in the Exploration Extra-vehicular Mobility Unit (EMU) Demonstration (xEMU Demo) configuration on the International Space Station (ISS) in the 2023-2025 timeframe. The timeline for this effort has remained unchanged from last year, and is shown in Figure 1.

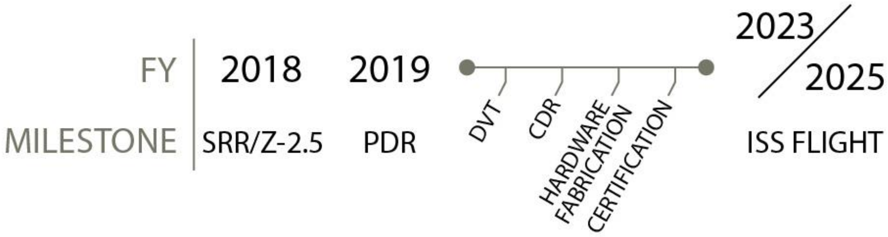


Figure 1: xEMU Demo Project Milestones

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

The Systems Requirements Review (SRR) for the Exploration EMU (xEMU) Demonstration (xEMU Demo) was held in February 2018, which set the baseline high-level system requirements in accordance with which component specifications were developed and allowed design maturation to continue.

As defined previously, the scope for the xEMU Demo configuration for the Advanced EVA Pressure Garment team is an advanced upper torso connected to an ISS EMU Lower Torso Assembly (ELTA).[1] The xEMU Demo architecture is shown in Figure 2.

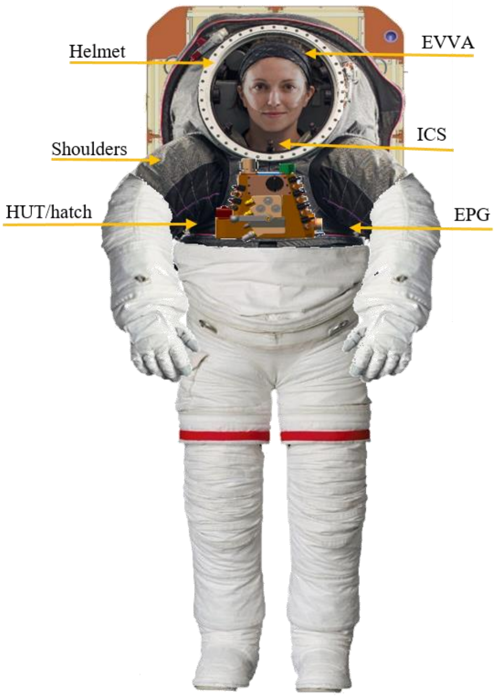


Figure 2: xEMU Demo Architecture

The Pressure Garment System being developed for the xEMU Demo includes:

- 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)
- Wired Heart Rate Monitor (WHRM, formerly referred to as 'Biomed')
- Environmental Protection Garment (EPG) with integration that mitigates dust

In 2018, effort was focused on design, fabrication, assembly and test of the Z-2.5 as a means to mature the design of the Exploration Extra-vehicular Mobility Unit Demonstration (xEMU Demo) architecture. Geometry changes necessitated by observations made during the Z-2 Neutral Buoyancy Laboratory (NBL) runs motivated an iteration prior to the xEMU Demo Preliminary Design Review (PDR).[1,2] Therefore, the purpose of the Z-2.5 prototype was to provide confidence that the changes made to the geometry both addressed the issues observed during the Z-2 testing and are acceptable to users. Additionally, Z-2.5 work frequently doubled as design maturation effort for components toward the PDR and Design Verification Testing (DVT). For example, the first proto-type of the xEMU Demo Extra-vehicular Visor Assembly (EVVA) was built for Z-2.5. The Z-2.5 configuration and components will be discussed. Progress being made toward the xEMU Demo DVT configuration that is not covered in the Z-2.5 configuration discussion will be reviewed, as well. As summary of the Z-2.5 component iteration status is given in Table 1.

Table 1: Z-2.5 Component Iteration Status

Component	Iteration Status
HUT	iteration from Z-2 hardware
Helmet	iteration from Z-2 helmet
ICS	iteration from Z-2 hardware
Shoulders	pre-existing hardware

WHRM	first iteration volumetric mock-up of xPGS Demo WHRM
LCVG	EMU LCVG with simulated auxiliary connector and lines between LCVG and hatch
EPG	iteration from Z-2 hardware, shoulders used pre-existing TMG

Of course, beyond the xEMU Demo work, additional requirements and challenges exist. The Advanced Pressure Garment Team continues to press onward to future mission with technology development efforts. In 2018, the team was able to initiate with a grant funded by NASA's Space Technology Mission Directorate (STMD), a project titled the 'Lightweight and Robust Exploration Space Suit (LARESS)' project. The work being proposed in this effort is discussed, as well as other additional technology and exploration development efforts.

II. Z-2.5 Modifications based on Z-2 NBL Test Results

The Z-2 NBL testing identified four primary areas of improvement that were addressed by the Z-2.5 design, as follows:

- Decrease System depth to ease ISS airlock egress/ingress
- Improve integration of the rear-entry upper torso with the EMU Lower Torso Assembly (LTA)
- Reduce the helmet bubble worksite interference
- Improve In-suit comfort during 1-g testing

A. Decrease system depth to ease ISS airlock egress/ingress

In order to reduce the depth dimension of the suit system, the PGS team changed the hatch and neck ring angles as shown in Figure 3. 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.

NBL tests of Z-2.5 will assess the effectiveness and acceptability of the changes Figure 3 illustrates the major changes made to the HUT geometry, with the Z-2.5 geometry highlighted with the red wire frame. The hatch angle was rotated toward the vertical. This change reduces the front-to-back dimension of the suit, shown in Figure 4, which is expected to enable easier ISS airlock hatch egress and ingress.

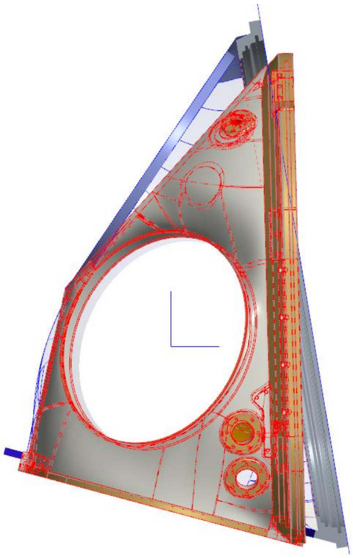
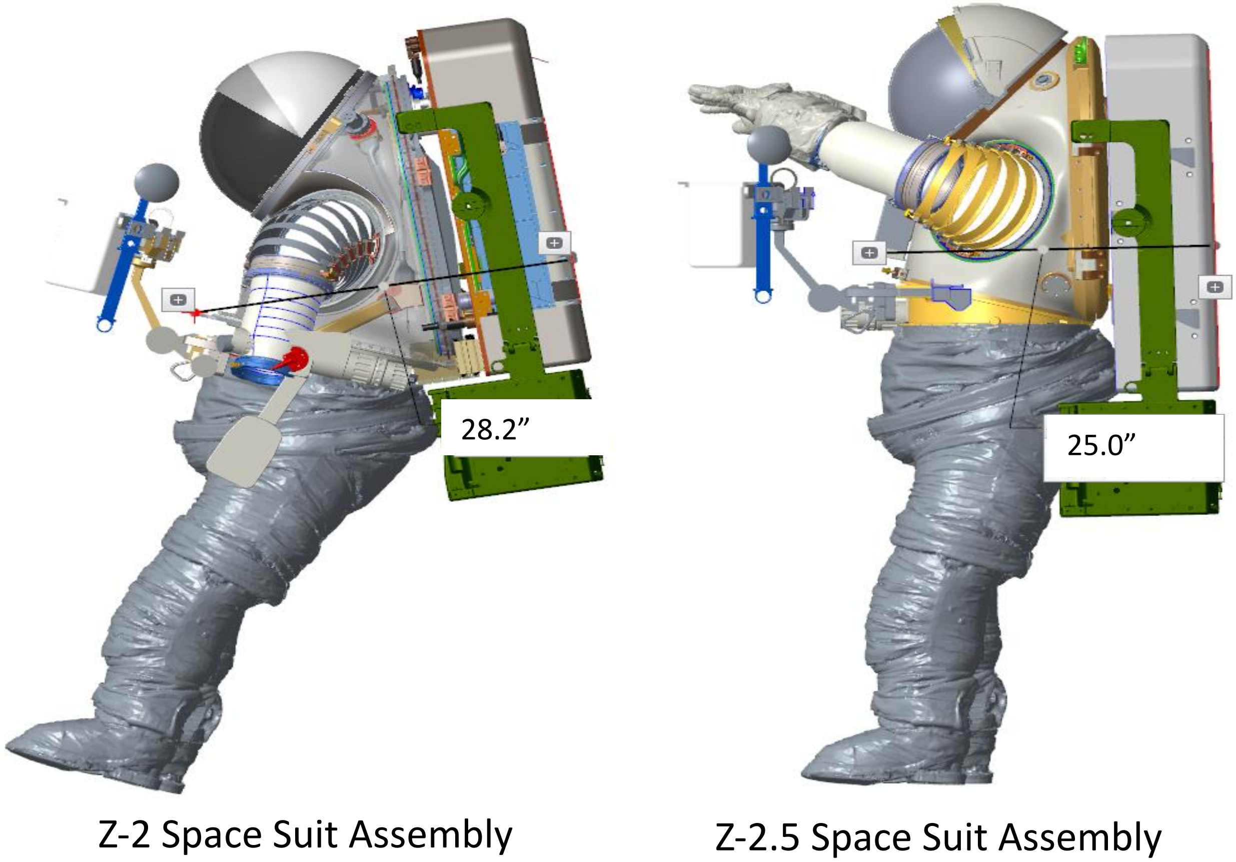


Figure 3: Z-2.5 HUT Geometry Changes



Z-2 Space Suit Assembly

Z-2.5 Space Suit Assembly

Figure 4: Suit depth decrease and posture change from Z-2 to Z-2.5

B. Improve integration of the rear-entry upper torso with the EMU Lower Torso Assembly (LTA)

Figure 4 also illustrates the effect of the addition of the waist wedge, which changes the posture from the piked position of the lower torso in the Z-2 EMU LTA configuration, to the much more straight posture of Z-2.5 due to the inclusion of the waist wedge. Figure 5 is a closer view of the wedge. During Z-2 testing, it was observed and subjects commented that they were placed farther back in the upper torso than desired, which affected reach and field of view. It was determined that the EMU LTA interface that was made on a very short schedule to adjoin the EMU LTA with the Z-2 upper torso did not account for the difference in interface angle between the two assemblies. For Z-2.5 the wedge was designed to allow the EMU LTA to be attached to the advanced upper torso at the same horizontal angle it is interfaced to the EMU. The wedge allowed subjects to assume a more forward position in the suit.

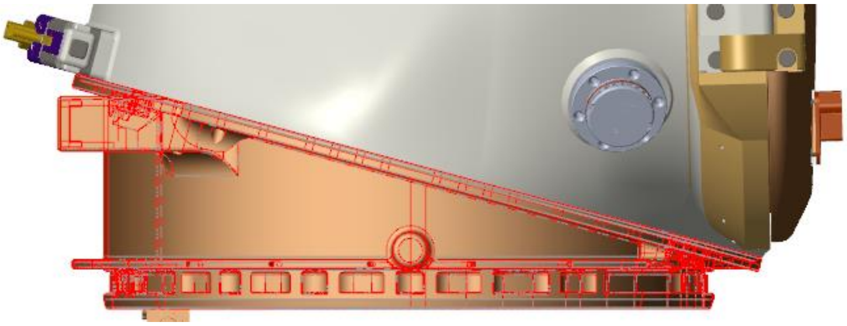


Figure 5: Z-2.5 Waist Wedge

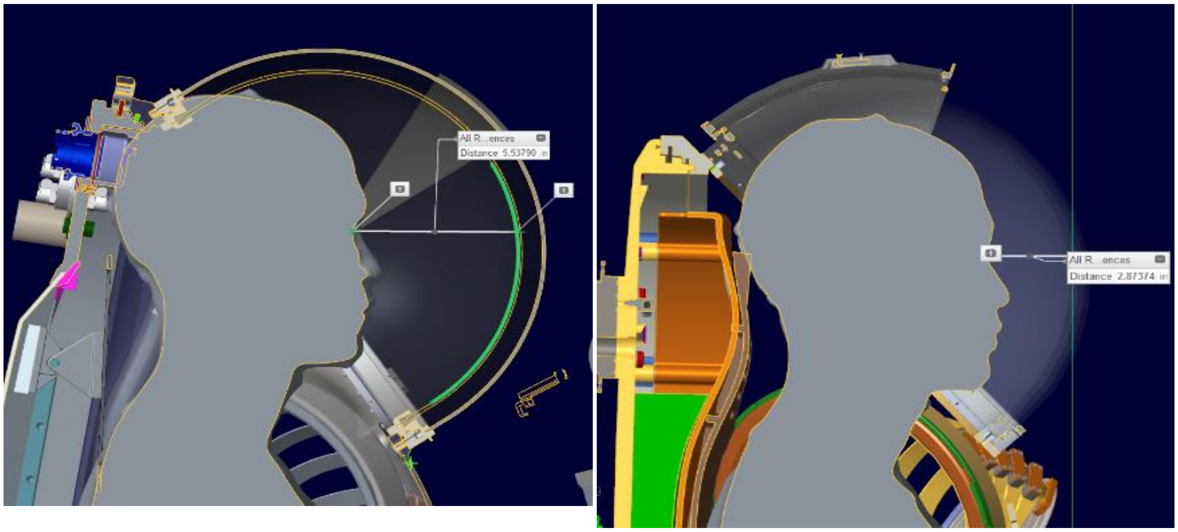
C. Reduce the helmet bubble worksite interference

Several design changes were made to address concerns regarding the protrusion of the helmet bubble into the suited crewmembers work envelope. The problem was severe enough that for one subject in the Z-2 testing the protrusion was caused a subject to impact their hands, which were holding onto a handrail. The change made was to make the neck ring angle shallower as shown in Figure 3, had dual purpose to decrease helmet protrusion. Another major change was that the helmet size was changed from an 11 inch short axis to a 10 inch short axis on the ellipsoid, while maintaining the 13 inch long axis. When the helmet was formed with the inch shorter short axis, the depth of the helmet was reduced.

D. Improve in-suit comfort in 1-G testing

During Z-2 testing, especially when face down, subjects noted pressure points on their chest. In the Z-2.5 design the effort was made to provide a friendlier interface with two changes. First was to remove unneeded features from the EMU scye bearing and the scye retainer ring that allowed to reduce the intrusion of the internal scye bearing interface. In addition to making a smoother interface, this change also contributed to improved subject positioning within the suit. Additionally, a cover was placed over the Display and Control Unit (DCU) fittings to further smooth the internal interface of the HUT.

In summary, the combination of the neck ring angle, addition of the waist wedge, reduction of the helmet size, and reduction of the scye bearing depth allowed subject to obtain an improved in-helmet location as shown in Figure 6. Figure 7 presents the Z-2.5 hardware configuration upon assembly into the upper torso and the full pressure garment.



Z-2 Z-2.5

Figure 6: Z-2 and Z-2.5 in-helmet head position

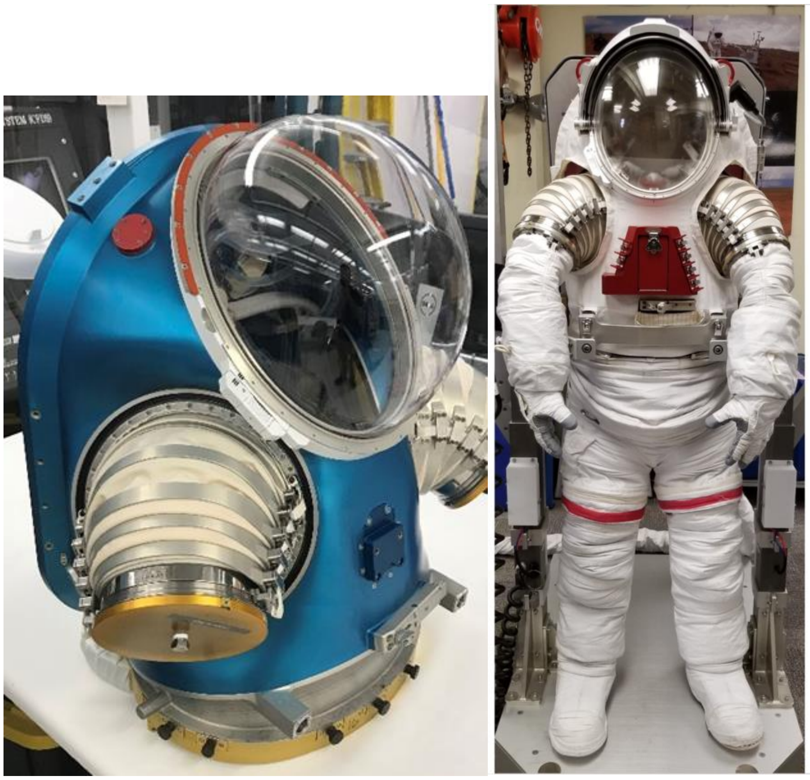


Figure 7: Z-2.5 xEMU Demo configuration

III. Description of the Components Included in Z-2.5

A. EVVA

The EVVA tested with Z-2.5 was the first iteration of the EVVA for the xEMU Demo project. Development of the EVVA was initiated during Z-2 testing, where fabric sections simulating the field of view (FOV) occlusion created by an EVVA were assessed. Based on an angle of 60 degrees as being an acceptable amount of occlusion, an EVVA was designed that features a sun visor broken into sections so that, when stowed, is entirely within the shell of the EVVA.[2] The sun visor was designed to be activated by a handle located on the left side near the neck ring, as seen in Figure 8. The acceptability of the intersection of the sun visor sections within the FOV will be evaluated during Z-2.5 testing, including during NBL testing. This is currently recorded as a risk for the design. Sun shades are included in the design, similar to the ISS EMU, at center and right and left sides. These are actuated manually with tabs using tabs on the shades in the Z-2.5 design. The EVVA includes a band that serves as a developmental interface for the lights and camera placement. Generic mounting interfaces on the band allow for a variety of light and camera positions to be evaluated.

Figure 8: Z-2.5 EVVA

B. ICS

Various upgrades were made to the ICS for Z-2.5. With the reduction of the helmet ellipsoid short axis dimension, it was determined necessary to remove the speakers of the ICS from the location on the helmet ring as configured in Z-2. The speakers were moved to the HUT, just aft from their location on the helmet ring for Z-2. New speaker enclosures were designed and implemented, which incorporates a hydrophobic barrier. New microphones were selected to provide improved performance. The new microphones exhibit improved EMI resistance and passed heavy ion radiation testing. Similar to the speakers, the microphones are mounted in an enclosure with a hydrophobic barrier. Both the microphones and speakers demonstrated acceptable responses during operation at low atmospheric pressures.

C. Shoulder

The external link rolling convolute shoulder has been shown to be effective across the Mark III Space Suit Technology Demonstrator and Z-2 prototype. Pre-existing shoulder hardware was re-purposed for use with the Z-2.5. This hardware was very similar to that used on Z-2.

D. Wired Heart Rate Monitor (WHRM)

A trade study, informed by a 2018 market survey and proton radiation testing results of potential components selected the component design approach for the Wired Heart Rate Monitor (WHRM), which was formerly termed the ‘Biomed’. The hardware consists of a chest strap with sensors and a small electronics module. The design combines Commercial-Off-the-Shelf (COTS) components with modifications necessary to adapt the hardware for the space suit application. The COTS components typically operate wirelessly with Bluetooth, which must be changed to a wired system for use within the pressure garment. A working prototype could not be accomplished for inclusion in Z-2.5 testing. However, a volumetric prototype is being included in NBL testing in order to obtain comments from test subjects.

E. EPG

As the focus of the EPG has been exploration forward, the focus has been on DVT products. In support of Z-2.5, a HUT cover layer was produced for the Z-2.5 testing, excepting the shoulders, which came with an EPG that is constructed with the EMU lay-up.

F. LCVG

Initially, Constellation LCVGs were intended to be used in the Z-2.5 testing. However, schedule issues and uncertainties with this configuration led the team to use EMU LCVGs with mocked-up auxiliary lines in the Z-2.5 tests.

IV. Additional xPGS Demo Design Maturation Efforts in Preparation for PDR

This section describes design maturation efforts beyond the work performed in support of the Z-2.5 configuration.

A. HUT

The Z-2.5 HUT was manufactured from aluminum as a means to achieve timely manufacture for testing this year. The baseline architecture for the xPGS HUT is a composite structure. A composite of fiberglass will be utilized for the xEMU Demo; although, it does not provide the weight savings benefits of other composite lay-ups, it will meet the impact requirements. Thus the effort for the xEMU Demo will focus on manufacturability, rather than selection of the final composite lay-up due to schedule. The lessons learned from manufacture and use of the composite during the xEMU Demo mission will inform the design of the xEMU utilizing a light-weight, robust composite structure.

B. EVVA

Efforts to identify the placement of the lights and cameras on the xEMU Demo configuration continue. The Informatics team continue to work with the PGS team to assess various placement options and understand interferences. A primary interference to be de-conflicted is the placement of the low-flow purge valve and that of the lights and/or camera. The low-flow purge valve is located on the right-hand side of the upper torso aft of the neck ring, and alternative location options are undesirable.

While a mechanical design is designated for the xEMU Demo configuration, the PGS team anticipates a new technology to address the challenges of a surface environment for the xEMU. To this end, a call for Small Business Innovative Research (SBIR) proposals for electrochromic visor technologies was posted for the PGS team in 2018. Electrochromic visor technologies are anticipated to be a viable solution for operation of visors in a dust environment. Two proposals were funded to investigate two different technologies and to understand the scope of the challenge of incorporating the technologies into the helmet geometry.

C. **ICS**

While test subjects, including crew members, have unanimously preferred the ICS over the Communication Carrier Assembly used with the ISS EMU due to increased comfort and head mobility, the open architecture of the system does increase the occurrence of echo. Operational concerns with line echo and acoustic echo, have led the ICS team to assess design choices to mitigate the concerns. In brief line echo and acoustic echo are defined as below and in Figures 9 and 10.

- Line Echo: Audio feedback induced by coupling between speakers and microphones AND microphone audio is transmitted back to speakers as side tone
- Acoustic Echo: Echo induced by speaker audio coupling to microphone

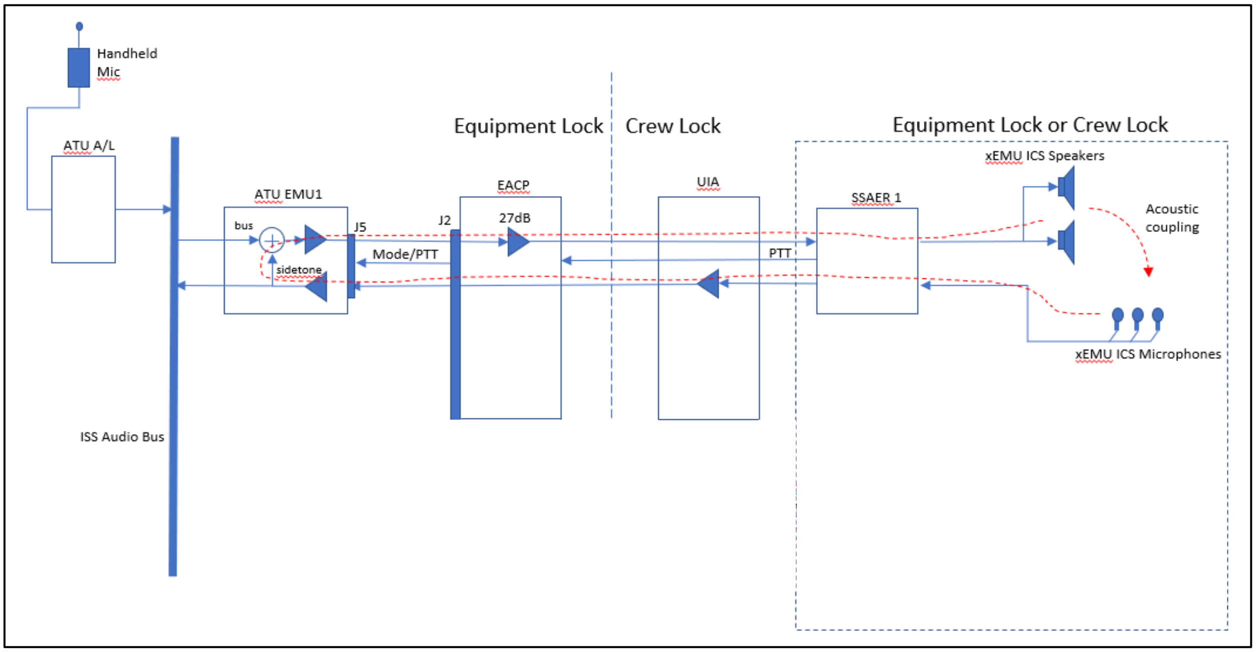


Figure 9: Illustration of Line Echo Example for the xEMU Demo

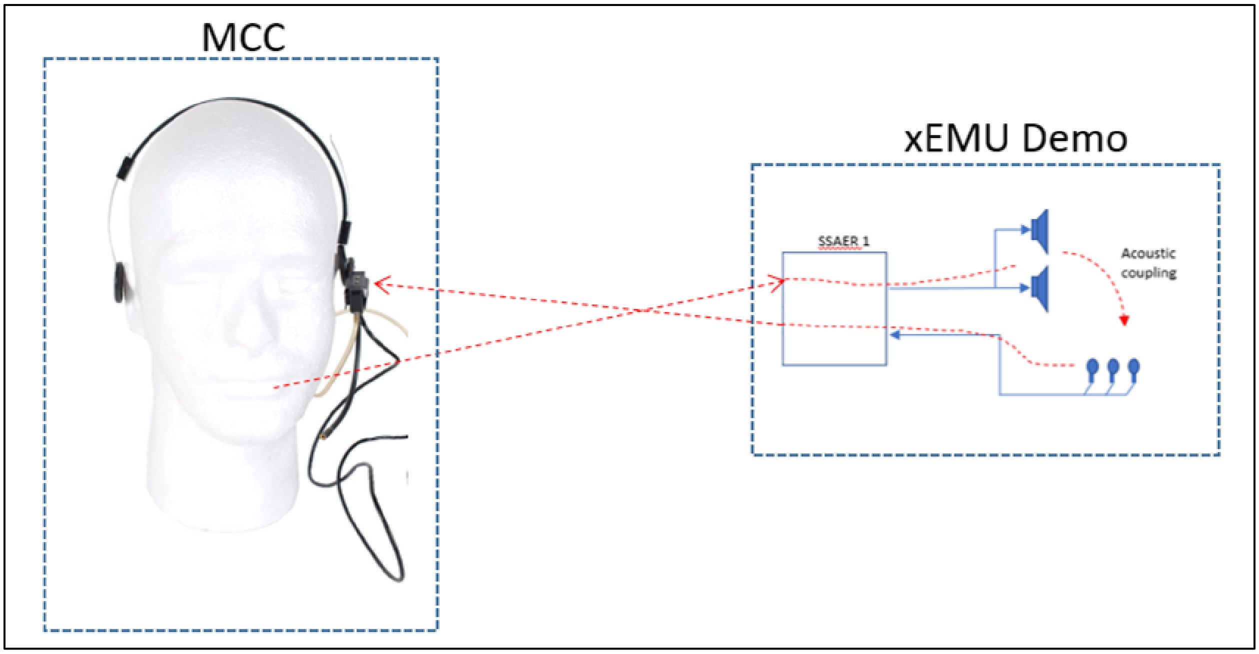


Figure 10: Illustration of Acoustic Echo Example for the xEMU Demo

In coordination with the PLSS team, design options and test results to assess the options were reviewed the teams agreed to pursue implementation of digital sound processing algorithm for echo cancellation in the Space-to-Space Advanced EMU Radio (SSAER) based on its initial demonstrations of effectiveness, extensibility to future missions, ability to address echo is a variety of operational modes, and its limited impacts to current ISS hardware, the suited crew member, the mission control center, and PLSS power draws. However, this option does increase the complexity of the SSAER and incurs the software flight certification process.

D. **Shoulder**

As pre-existing hardware was utilized for the Z-2.5, this allowed progress to be made toward the DVT hardware design. Two primary hardware risks are being addressed: impact and durability.

Impact

The component owner was concerned that the external link rolling convolute shoulder design may be vulnerable to kick load requirements. If a ring(s) of the shoulder were to be deformed upon impact, the shoulder may become bound, and potentially immobile. In order to answer the question prior to PDR, a preliminary finite element analysis (FEA) was performed. High stress areas were identified and the design is being changed to reduce the stresses, thus improving the performance of the shoulder under a kick load. Moving forward, the iterated design will be undergo a full FEA. Based on the results, additional design changes may be required before the design is fabricated for DVT and the shoulder undergoes an impact test.

Durability

Based on some wear observed to the shoulder textiles from the inside of the pressure garment during Z-2 NBL testing, durability is being addressed as a concern in the shoulder design. Prior to fabrication of the DVT hardware an unmanned cycle test will be performed. Currently the cycle tester is being restored to service for this test. If wear is observed during the unmanned cycle test, a change to the shoulder fabric layup or the insertion of a liner to the shoulder may be needed to improve durability.

E. **WHRM**

The design of the WHRM progresses with a prototype expected in proximity with PDR. This prototype will be utilized in DVT.

F. **EPG**

Concurrent with the Z-2.5 cover layer fabrication, which matured the HUT EPG patterning, a trade among the segmenting options for the sleeves has been on-going. The comparative benefits and challenges of the options for fabrication, dust mitigation, mobility, and sizing were assessed. The trade is being informed by a design effort to determine the methods to attach the EPG to the suit structure in ways that support dust mitigation requirements. The EPG team is coordinating with other component owners to incorporate interface features onto the DVT HUT and shoulders, should they be needed.

G. **LCVG**

Initially, the team had hoped to develop a single xLCVG to serve for both the xEMU Demo and xEMU configurations. Several directions to this end have been investigated. Modifications to existing hardware and new configurations from vendors have been considered.

The Constellation LCVGs were modified by removal of the original ventilation tubing, which was capable of being pinched closed, and subsequent addition of ventilation lines from the EMU ventilation system. A 3D printed auxiliary loop connect replaced the existing connectors. These modified LCVGs were intended to be used in the Z-2.5 NBL testing. However, schedule and commonality of testing considerations for DVT led to the decision to use the EMU LCVG with simulated auxiliary lines and connector as more relevant a volumetric and crew interface analog.

A dual path effort continues to an xLCVG with the exploration of alternate garment, ventilation tubing, and water line effort on-going. A pair of LCVGs were received from a vendor and assessed. Additional vendors supported the team in the development of the LVCG connectors, for both the primary and auxiliary loops, and in the design and assessment of new ventilation tubing. The team has performed tests of water loop tubing to down select to a new tubing.

A decision will be made prior to the xEMU Demo project Critical Design Review as to what LCVG will be carried into certification testing.

H. **Requirements resolution: Manloads**

A requirement that has yet to be completed is that of manloads. There are two types of manloads. Isometric manloads are the loading a person can impart on the suit, usually due to the suit being sized short for the wearer. Externally-induced manloads are created from an external force. For example, it is the force imparted on the suit when a person is secured, usually in a foot restraint, and holding onto an object that is moving away from them. In general in addition to suit sizing/fit dependency as in isometric manloads and external loads impacts for externally-induced manloads, manloads are dependent on the geometry and materials of the pressure garment. Thus, for the xEMU Demo project's new architecture, new manloads are being determined.

The team reviewed the manloads test performed on the Space Shuttle EMU configuration following missions such as the Intelsat recovery mission and the analysis that was performed when the EMU was modified to meet ISS requirements. The limiting factor on the achievable loads is the hand breakaway strength. Hand breakaway strength is the load at which the hand can no longer hold onto something being pulled away. Hand breakaway strength is not to be confused with grasp strength, which is the force to which the hand can squeeze an object. In 2018, a breakaway strength test was performed using subjects who fit in the Z-2.5. The results matched the maximum achieved during the EMU testing, which gave confidence that the Shuttle number was realistic. Additionally the mean hand breakaway strength generated was higher than that generated by the EMU manloads subjects, which indicated that the xEMU Demo manloads test would produce a number that can be used as a requirement.

Additionally, the test equipment for the manloads test has been designed. An adjustable foot restraint, instrumented brackets for the suit axial restraint brackets, and an interface for the handhold to the ARGOS, which is simply used as a calibrated tension loading device, have been fabricated for the test. The instrumented brackets were tested to verify that the loads will be accurately recorded. The manloads test using the Z-2 suit is planned for the spring of 2019 and will be discussed in a future paper.

I. **xPGS Demo Flight Processing Laboratory**

In preparation for DVT, Certification, and Flight hardware processing, the xEMU Demo team has been working to obtain and outfit a PGS Flight Processing Laboratory. Initially, the team considered combining the current research and development function of the Advanced Suit Laboratory with the flight processing function in Building 34, but space limitations and concerns regarding the co-location of machining capability with flight hardware processing led the team to look elsewhere. A space was obtained in Building 10 at the Johnson Space Center. The team is now in the process of outfitting the laboratory. The laboratory lay-out is proposed as illustrated in Figure 11. Phase I is to be completed in 2019. Phase II areas are anticipated to support certification, flight training, and flight processing. Flight hardware compatible ground support equipment will be designed and fabricated in 2019 to supply the laboratory. Also in 2019, major laboratory outfitting hardware procurements, such as a clean room and cage will be made, to meet the laboratory readiness schedule in support of DVT. The team plans to use the laboratory and procedures as a dry run for flight hardware processes.

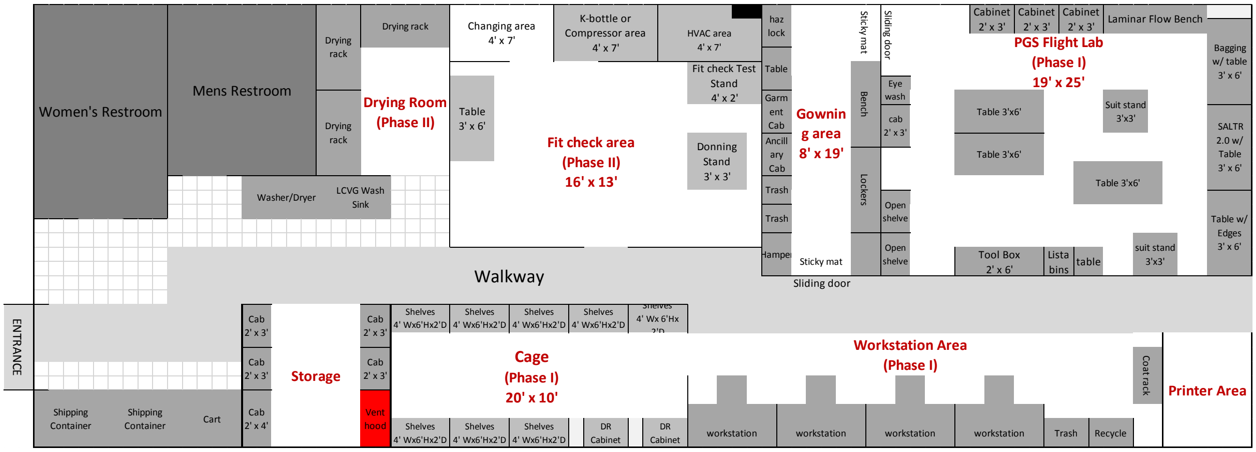


Figure 11: Proposed Layout for the xEMU Demo PGS Flight Processing Laboratory

J. Suit Technical Interchange Meeting

In November 2018, the PGS team presented a status to the EVA community, project stakeholders, and retired EVA consultants. Over two days the team informed the community of the progress made since the SRR. The Technical Interchange Meeting allowed the team to receive feedback in anticipation of PDR. Chief amongst the feedback was concern expressed regarding the ICS and the HUT composite. These concerns are being addressed, as described above, and the status will be presented at PDR.

An administrative challenge to the team has been its rapid expansion. The TIM served as an opportunity to introduce new team members, for them to present to the EVA community, and for them to obtain the broad perspective and status of the team's efforts. The team has exceeded 25 members. Figure 12 gives an outline of the xPGS team's composition. The speed with which new team members have been able to be productive and work as fully engaged teammate is a testament to the quality of new team members. The Ground Support Equipment team is an example of a team that is fully staffed with new team members, who came in with years of EMU experience, are making significant forward progress on the outfitting the flight processing lab, including the design and fabrication of breathing systems and other support hardware. Their timely efforts will ensure that the team is ready to perform DVT.

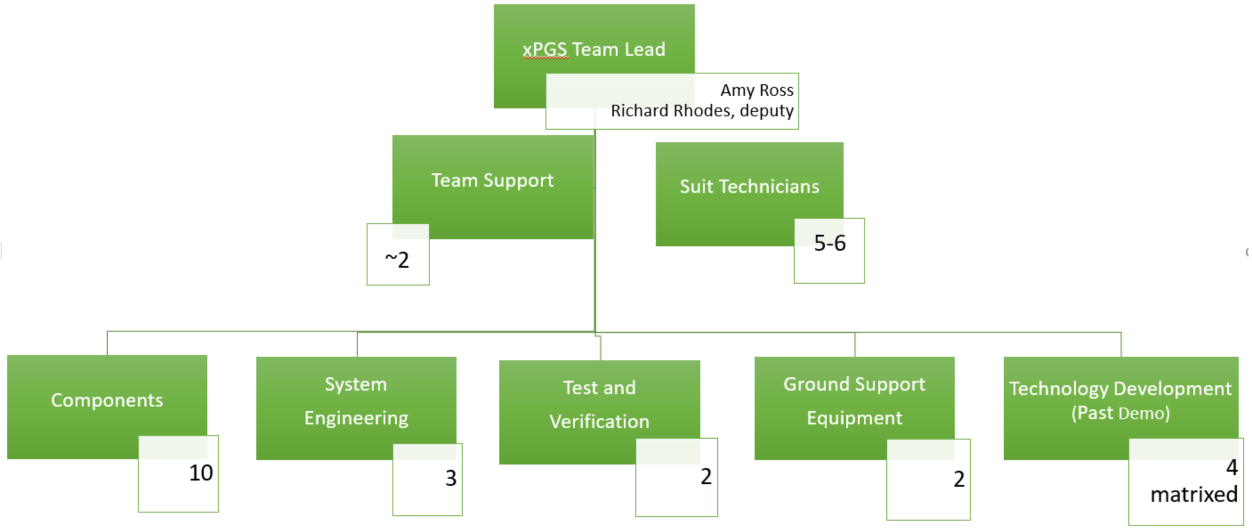


Figure 12: 2018 xPGS Team Organization Chart

V. Technology Efforts for xEMU and Beyond

A. Light-weight and Robust Exploration Space Suit (LARESS)

Safety of the crewmember and durability of the suit are paramount as we travel farther from Earth. The lunar and Martian environments offer several new challenges in comparison to microgravity operations, including the addition of a gravity field and the potential to fall and impact the suit structure on rocks. This possibility was realized several times during the Apollo mission as crewmembers fell frequently. The limited mobility of the Apollo space suit made the likelihood of falling fairly high. The Lightweight and Robust Exploration Space Suit (LARESS) project was awarded as a seedling task for FY19, with a pending proposal in for three additional years of funding. LARESS has four primary goals: 1) better understand the risk associated with falling on a planetary surface, 2) identify the most robust structures available that can be manufactured into the complex geometry of the space suit structure, 3) reduce the system mass to the extent possible, and 4) improve the mobility of the lower torso assembly so that the crewmember is less likely to fall on the surface.

To assess the risk of damage on the planetary surface the project will analyze potential landing sites on the moon and Mars and categorize the risk from the surface terrain and rock types. This analysis will be used to create a model that evaluates the risk of falling and damage to the suit at these sites. In parallel, the project will evaluate current and potentially new materials to best withstand the damage that would be sustained in these environments. Finally, the lower torso architecture will be evaluated and improvements will be made for extensibility and sizing. The end product of this project will be a new lightweight and robust space suit structure design, a new lower torso design, and a model to assess the risk of damage at planetary EVA sites.

B. Environmental Protection Garment (EPG) for Exploration Missions

The EPG team continues to make progress of research and development efforts on planetary surface EPG materials and design and general dust mitigation strategies. In 2018, the team was awarded a Center Innovation Fund Internal Research and Development grant to investigate the performance of spacecraft electrostatic discharge coatings to space suit fabrics. In the year-long project, the JSC team is collaborating with Glenn Research Center, Goddard Space Flight Center, and the Langley Research Center to perform proof-of-concept testing on material coupons to understand the dust mitigation properties and performance in the space suit application. Results will be reported at the end of FY19, which will inform future development.

Another proposal was submitted to the STMD's Game Changing Development program in 2018 with the goal of developing a lunar EPG material lay-up. A team consisting of six NASA organizations, consultants from five more, and three potential academic and government collaborators was proposed for the 3-year effort that planned to result in a technology readiness level 6, defined as "system validation model validated in simulated environment", product.

While funding was not obtained for this specific proposal, the team was motivated to developing collaborations to address the various environmental protection requirements for the EPG within NASA, the government and academia.

Finally, the SBIR/STTR program has continued to bear fruit for the team in the area of the EPG. A Phase II STTR has continued to study the application of a shear thickening fluid enhanced materials to the EPG lay-up[4].

The team understands that meeting lunar surface environmental protection requirements no longer a long-term effort, but a shorter term need, so they must continue to pursue creative means of EPG development.

C. xLCVG SBIR

A 2018 SBIR forwarded xLCVG design through development of LCVG water tubes with improved conductance. The progress made in the SBIR is discussed in the 2019 International Conference on Environmental Systems paper title. *Advanced Liquid Cooling and Ventilation Garment Using Thermally Conductive Tubing* (2019-ICES-175).

D. Mars 2020 SHERLOC Instrument Calibration Target Space Suit Exposure Experiment

2018 saw completion of the Critical Design Review, flight hardware fabrication, and certification testing for the Space Suit Materials Exposure Experiment for the Mars 2020 lander. Calibration target flight hardware is to be delivered in FY19 to the Jet Propulsion Laboratory for final testing and integration with the Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC) instrument. This year's accomplishments brings the five small space suit samples worth of human spaceflight hardware closer to Mars than ever before. Once on Mars, the spectra data obtained using the SHRELOC instrument from the samples as they are exposed to radiation on the surface of Mars will serve as the ground truth data to calibrate results of the simulated Mars surface radiation exposure to control samples on Earth. This data will be used to assess material durability for the Mars space suit fabrics.

VI. Conclusion

In conclusion, in 2018 significant design maturation was performed using the Z-2.5 development, as well as additional design efforts focused on PDR and DVT readiness. The results from Z-2.5 NBL testing and PDR in 2019 will place the xPGS Demo on a firm footing toward flight. Further, the advanced pressure garment team continues to look beyond the xEMU Demonstration project to technologies that address the gaps between the xEMU Demo and the xEMU. The team is working on funded work and pursuing new funding via proposals in support of meeting planetary surface suit requirements and technology needs.

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The authors also thank our industry partners whose work, dedication, and innovation is invaluable in forwarding the xEMU Demo and goals beyond. We cannot do it without you.

Finally, the xPGS Team wishes to remember Lynette Armstrong. She was only on our team for a short time, but her enthusiasm, her professional capability, and her thoughtfulness of others create an absence that we all miss very much.

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