2020 EVA System Maturation Team Gap List

T/D/K	Enabling/ Enhancing	Gap Name	Description	Status
D	Enabling	Dust Tolerant Bearings	Need pressure enclosure rotating bearings that prevent surface dust and regolith from entering the bearing race over extended hours and EVAs of long duration surface missions in order to preserve. After dust exposure, mechanism must fail gracefully, not catastrophically so as to maintain the torque and range of motion of the bearing within acceptable limits for use.	5/31/2016: A test procedure and setup has been developed to test the torque variance in wrist bearings when exposed to dust; it still needs to be validated. The High Performance Glove Disconnect (HPGD) System was developed in FY14 and included a dust seal. A revised dust-tolerant wrist bearing design is included in the ILC HPEG glove and will undergo testing in the summer of FY16. 7/18/17: Dust tolerant bearings are part of the space suit RFI being released in summer 2017. Must track EVA-RD-001 updates to understand whether this requirement will be enabling or enhancing for xEMU. FY18 plan includes refinement of test methodology. 9/11/2018: Dust-proof shoulder and upper arm bearings with dust-proofing are being procured for the xEMU Demo effort through phase III SBIR. Significant testing required to see if gap is closed with current design. 11/22/2019: Dust tolerant bearing designs are being incorporated in the xEMU design for 2024. Design Verification Testing to be performed in FY20 and FY21 will inform NASA as to any design changes that may be required to best mitigate dust intrusion into the bearing races. 12/10/2019: Delta SRR next week, confirm logic and future iterations on design may be needed to support later missions.
T	Enhancing	Plasma Protection	Need an integrated suit design that can withstand the plasma environment and protect the crewmember at each destination. System plasma shock dissipation and protection is used in conjunction with operational constraints. While the EMU is capable of operating in some cislunar plasma environments, enhanced capability is required for operational flexibility in more environments.	5/30/16: Phase II SBIR to address anti-shock coatings on suit hardgoods. CxP DSNE describes lunar environment with some limited maturity; document not finalized. Both AES EVA and CSSS have draft environment spec books that have been compiled from agency resources. Neither book is complete, nor endorsed. Neither project has significant resources available to finalize the books. We have had initial discussions with SERVI to address the knowledge gap/requirements definition. At this point we do not know how/if they will be able to help though. 8/8/17: SBIR Phase II completed and hardware is at JSC ready for testing. There is potential collaboration w/ EMU for testing and early demo/cert on ISS. TRL 3 9/11/18: Self-healing anti-shock coating for bearings developed on SBIR is part of the xEMU demo effort at this time. The gateway environment passes into the solar wake behind the moon and the plasma charging environment may become more pronounced. SSERVI DREAM 2 team recommended making the space suit exterior conductive, though this poses potential problems. IRD Funding awarded for partially conductive fabric coating in FY19 for potential use in plasma charge dissipation. Knowledge gaps exist in this area as well. 11/22/19: The need remains for effort to be dedicated to development of integrated plasma protection. A promising technology exists, but limited resources has resulted in lack of progress to date. The xEMU team is attempting to include an integrated plasma protection solution by qualification testing for 2023 suit deliveries. Closure Duration: 3-7 years.
K	Enabling	Inspired CO2 requirement	Need validated inspired CO2 limits that are relevant to suited operations. The current requirement set is based on wall-mounted sensors with no correlation to inspired vales.	10/24/2016: SA is aware of this disconnect and is tracking it on list of NASA-STD-3000 forward work. Some funding had been provided by HRP for this work. 9/11/2018: No census exists on the requirement, but research is ongoing. 12/10/2019: HSB discuss this tomorrow based off significant research and discussions on this requirement. EVA community has made great progress and could potentially close this gap soon. Closure Duration: 1-3 years.

2020 EVA System Maturation Team Gap List

T/D/K	Enabling/ Enhancing	Gap Name	Description	Status
D	Enabling	Mass/Strength Optimized Composites	Need mass/stress-optimized structures for upper torso and brief. Surface impact and fall requirements in conjunction with optimizing mass are the key driving requirements when selecting a technology.	10/24/2016: A small amount of effort has been allocated un FY17 to assess HUT redesign efforts to improve packaging and reduce mass. A proposal was submitted to GCD Program to request funds to specifically evaluate high strength, low-mass composite structures. Waiting to hear back on award. Additionally, this could also be addressed as part of overall EVA architecture trades on suit pressure, suitport/suitlock interfaces, pre-breathe time, etc. 7/18/17: Waiting to hear back on GCD seedling proposal evaluation. Currently have 3 Phase I SBIRs working on this topic. Phase I concludes in FY18 and will likely result in at least 1 Phase II proposal. 9/12/2018: STMD GCD seed funding awarded for FY19 for composites development using new/optimized materials. Z-2.5 HUT is aluminum, xEMU DVT HUT may be S-glass until new composites setup is optimized. 11/22/19: There is an effort funded by GCD that is testing material samples and is returning promising results. Funding for the effort ends after FY20. Without continued research a new material will not be available by 2028 for infusion into the xEMU. Closure Duration: 3-7 years.
D	Enabling	Dust Tolerant Mechanisms	Need protection of relief valves, purge valves, disconnects, actuators and other mechanisms to preclude dust from hampering motion / function. These types of functional mechanisms are required for long-duration EVA operations on the planetary surface.	10/24/2016: Active dust clearing function (forced gas) was assumed during early connector designs for CxP. This feature is not currently included in the xEMU SCU connector. Two Phase 1 SBIRs (Airlock, Inc. and Honeybee) were funded this year to investigate possible design solutions. PGS has not yet invested much effort in this area to understand scope/difficulty of this problem. It may require actual technology development to solve. 9/11/2018: SBIR work for dust-proof connectors completed (insert more information). PGS is currently revising designs for dust-proof interfaces and bearings as part of the xEMU Demo effort. Current mechanism designs must be tested for dust compatibility. 11/22/19: Limited effort on this area is included in the xEMU 2024. xEMU DVT Testing will identify design and technology sensitivities for the focus of future work.
K	Enabling	Gateway Contingency EVA Requirements	What is needed to use a LEA suit for EVA, as is being discussed for Lunar Architecture or Gateway Internal EVA? Given standard hatch diameters, assuming an xEMU does not fit, what LEA capabilities are needed to perform these EVAs? Determination of the hardware solution requires expected EVA duration, CO2 washout, task performance etc. Capsule-based EVA on a limited-duration or contingency basis is more readily achievable. There would be significant challenges in meeting ISS-style EVA requirements with an OCSS-style system.	EC5 performed significant initial work toward LEA EVA capability in support of the ARCM concept in 2013 and 2014 use. Crew consensus memo indicates the MACES architecture is acceptable for use in contingency scenarios with some modification. These comments are largely applicable to the OCSS system as well. The OCSS team believes that for contingency EVAs under 4 hours with no liquid cooling requirements, the system design could be very simple and potentially similar to the Gemini configuration. There are no open technology gaps required to meet properly constrained contingency EVA requirements. 12/10/2019: Gateway IAC4 analysis is being done to provide contingency EVA capability to Gateway. Until Gateway airlock arrives (2028) there are concepts to utilize the lunar lander for microgravity EVA at Gateway. Further work needs to be done on this topic.
T	Enabling	Tool Transport on Surface EVAs	Need EVA tools caddy device for each destination based on results of a trade study to determine if, and what type of, a tool caddy is needed, as compared to leaving EVA Tools on the local vehicle (rover, truss-mounted tool box, etc.) and having the crew translate/walk back and forth with tools in hand.	NEEMO 18-19 evaluated a prototype EVA Sample Bag Dispenser. NEEMO 20 evaluated an Integrated Geology Sampling System that included a "briefcase" that housed various sampling end effectors. NEEMO 20 evaluated utilizing a robotic asset (ROV) to carry tools and samples for the EVA crewmembers. NEEMO 21 took initial look at sled/cart options for large equipment transport using several variations: No wheels, 2 wheels, 4 wheels, rope handle, and solid handle (handles were an issue). Tool caddy worked well, but adjustability will be a critical feature to accommodate different crew preferences; packing plan for caddy was critical. Evaluated sling bag options for small items and easy access (sample markers, hand tools, electronics, etc.) - conceptually good, but challenging to use with the dive system. Need to determine the tool compliment for each phase of the EVA operations, and how those tools are best transported and stowed. NEEMO 22 evaluated Modular Equipment Transport System (METS) for large and small equipment transport. Included includes 4-wheeled transporter and crew-worn tools on forearm and thigh. Recommendations/Forward Work: Look into developing a harness that could be attached to the suit or worn over the suit in order to carry tools. Knowledge gap for Mars environment: Need definition for amount of in-situ analysis to be performed on samples. Need definition of level of containment for samples and need programmatic definition of contamination limits for forward and reverse contamination. Need EVA Tools to perform in-field sample assessment (high grading). Need EVA

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				Tools to package and label samples for return to Earth. Need an EVA Tool set to store and manage volatile samples.
K	Enabling	Incapacitated Crewmember Operations	Integration: Need to develop methodology for transfer/transport of an incapacitated crewmember at each destination and how to transfer them onto the ingress/egress hardware, or through side hatch, and doff suit. Knowledge: Rescue protocol has not been identified for each destination. Determine how to address rescue of incapacitated crewmember on single person EVA scenarios. How does a 5th percentile strength crewmember rescue a 95th percentile mass crewmember?	Past analogs have assessed portions of rescue (Devon Island/Haughton Mars Project 2006, NEEMO 14, LER testing in JSC B9, DSH testing). During LER timeframe, work was done for crew rescue in lunar scenarios; however, preliminary assessments of ingress via suit port vs. side hatch showed suit port ingress as more acceptable. SEV design changes were implemented in aft cabana based on analog testing to assist in lifting and aligning incapacitated crew with suitport in partial gravity. Needs further work geared toward different DRMs and looking at varying numbers of crew, surface assets, and surface terrain types. NEEMO 20: Add results from N20. Add findings from NEEMO 21 and 22; LESA. Add recommendations (if agreed upon) for next steps from Incapacitated Crew Rescue EEWG presentation by S. Chappell Unfunded. Microgravity knowledge gap: Closed Surface operations knowledge gap: Open
K	Enabling	Required Suit System Center of Gravity and Mass	Need to determine the integrated center-of gravity and mass limitations for effective planetary exploration. How does the gravity field effect the performance of a given suit? Will the same suit design work on the surface of the Moon and on the surface of Mars?	11/15/2016: Z-2 mobility will be evaluated at reduced gravities at the ARGOS facility in 2017. 11/22/2018: Z-2 Testing did not occur at the ARGOS in 2017, there are no current plans for ARGOS planetary configuration testing for xEMU.
T	Enhancing	Alternate Pressure Garment Structural System	Need alternates to polyurethane-coated nylon/spectra combination. The goal of the effort is to seek improvements to manufacturability, cost to produce, durability, and joint torque.	11/22/19: Gap remains with no progress made toward closure.
T	Enabling	Lunar Surface EPG Shell Material System	Need suit material layups capable of long duration exposure to dust, and abrasive activities without compromising mobility (walking, kneeling, etc.). Integrated design and constructions methodologies should mitigate penetration of abrasive material (over-tape out-layer stitch holes, environmental seals, etc.).	5/31/2016: Abrasion testing of the HPEG-ILC prototype layups will occur in the summer of FY16. A test procedure and setup has been developed to expose materials to wear from abrasive dust. This procedure and setup has been demonstrated in one series of tests, but the findings have yet to be analyzed in detail. It is anticipated that iterations will be necessary. SBIR phase I complete with phase II in progress to address self-healing bladder and cut-resistant RTV replacement for glove palms. 7/18/17: HPEG final report expected 9/30/17 Divide this into Moon and Mars specific EPGs 9/12/2018: Phase II STTR for Lunar surface EPG system is in its 2nd year. Limited EPG development in xEMU project. 11/22/19: There is an active STTR in this area. xPGS team resources are limiting progress made. The baseline for xEMU 2024 is use of the ISS EMU materials lay-up. Significant forward work remains to provide new materials for lunar missions post-2024.

2020 EVA System Maturation Team Gap List

T/D/K	Enabling/ Enhancing	Gap Name	Description	Status
T	Enhancing	Pressurized EVA Sizing Adjustments	Need ability to adjust fit of gloves and boots while pressurized. This particularly critical for suitport operations but would benefit traditional EVA ops as well.	11/15/16: Z2 includes second generation adjustable boot design that works well at 4.3psid but is very difficult above that pressure. Adjustment mechanisms are included on HPEG gas-pressurized gloves but have not yet been tested (planned for late FY17). 7/18/17: This is an enhancing capability unless suitport concept is implemented. 9/12/2018: HPEG final report completed, includes some recommendations on sizing. EVA boots are a phase 1 SBIR topic for FY19. 11/22/19: No progress.
T	Enabling	Body Waste Management Solutions	During the xEMU ISS Demo SRR there were several RIDs written against the NASA-STD-3001 Volume 2 allocation matrix in the PTRS with regards to missing flow down of body waste management standards. Originally SSP 51073, Exploration EVA Suit Systems Requirement Document Baseline listed these standards as Applicable, but met through operational mitigation. The xEVA System Panel was assigned several actions to address the flow down of these standards. SA assisted in burn down of these action items and brought the EVA/SA consolidated recommendations to the FACB on 09/19/18 for final approval. This resulted in generation of a Memo and associated enclosure. An Action was assigned to SA at the 11/29/18 TCM to review all of the NASA-STD-3001 V2 Body Waste Management standards applicable to the EVA Suit and reach an agreement on the values associated with EVAs (e.g. for a single EVA). These should be updated in the next revision of the NASA-STD-3001 V2 Section 11 standards for the suit. There are a couple items that would lead to an EVA terminate, such as vomit and diarrhea. Need to ensure that there is a focus urine management.	New Gap per SSP 51073 Revision A process.
K	Enabling	Orthostatic Intolerance Countermeasures Solutions	It was decided that during the SSP 51073 Exploration EVA Suit Systems Requirements Document to Revision A Technical Concurrence Meeting (TCM) on 11/29/18 to open a new gap for Orthostatic Intolerance Countermeasures solutions. This gap is to address a comment received during the CR review that requested to change the applicability of the NASA-STD-3001 V2 flow down of standard V2 7042 to the PTRS from Applicable to Not Applicable as this capability was nominally addressed by the Launch, Abort, and Entry (LEA) suit. Orthostatic Intolerance Countermeasures are not applicable for microgravity EVA operations. During the Dec 11, 2018 EEWG, discussion to make this gap broader, as Orthostatic Intolerance is just one piece of a bigger countermeasure and physiological deconditioning picture.	New Pending Gap per SSP 51073 Revision A process.
T	Enabling	Non-vacuum Continuous CO_2 Removal	Need continuous CO_2 removal capability that can operate within the Martian atmosphere. The Rapid Cycle Amine (RCA) system in its current form does not work in the Mars environment, and either a new approach, sorbent, boost compressor, or thermal swing is required.	7/18/17: This will be brought forward as FY18 SBIR subtopic in EVA area. Specific areas of interest include: a. Update/supersede SA9T state of the art i. Improvements in amine uptake ii. Alternative processes such as temperature swing adsorption, selective permeable membranes, etc. b. Augment SA9T operation using thermal swing adsorption approach c. Augment SA9T operating using boost compressor to enable pressure swing operation in the Martian atmosphere 12/18. 2019 Phase 1 SBIR was released under the Exploration Portable Life Support System (xPLSS) for deep space and surface missions subtopic (ID H212). Section 2.0 describes the requirements for a boost compressor to enable CO_2 removal in partial atmosphere in combination with the RCA system. Estimated gap closure duration 3-5 years.
T	Enhancing	Trace Contaminant Removal	Need a continuous trace contaminant removal capability that is regenerative (not a routinely consumable item). Activated charcoal is the state of the art and provides a logistics hit to all exploration reference missions to remove NH_3, CO, CH_2O, CH_3SH, etc. The minimum objective would be to remove all of the significant compounds that threaten to exceed the 7-day SMAC during an EVA with the optimal objective to enable removal of less significant compounds. Ideally, this is either a passive membrane or actively switched regenerating beds that can be paired with the CO_2/RH removal approach.	12/2018 Work on regenerable TCCs is currently underway on SBIR contracts. A phase one SBIR was completed but a Phase-II was not awarded. Estimated closure duration 3-5 years.

2020 EVA System Maturation Team Gap List

T/D/K	Enabling/ Enhancing	Gap Name	Description	Status
D	Enhancing	Radiation hardened DC/DC Converters	Need radiation-hardened, isolated DC/DC converters with an efficiency of >80%. This efficiency gain would enhance the performance of the PLSS by reducing the power consumption of the system as a whole. For spacesuit life support systems, there are a number of small point of load applications such as smart instruments, controllers, etc. that require small, low power output, isolated DC/DC converters. With derating and the limited offering available from existing catalog parts, the available efficiency is often much lower than the rated efficiencies advertised for the part of 70-80% as the converter losses become a larger part of the overall output dropping the realized efficiencies below 65%. Current state of the art is ~70% for 28V to 5V DC/DC with MS Kennedy P/N BBF2805S as an example.	7/18/17: Initial round of testing on singular COTS components were promising (ref. PLSS tech memo) 9/12/18: Submitted as a 2019 SBIR Phase I topic on H212, proposal call attached. Estimated closure duration 2-3 years.
T	Enhancing	PLSS Batteries	Need safe, high-energy density power sources that are rechargeable post-EVA. The current state of the art is Li-Ion batteries with cell level energy densities of ~200 Wh/kg but packaged energy densities of ~130Wh/kg after addressing mitigation for thermal runaway. Enhancing battery performance can reduce PLSS mass and volume, or allow for additional power capability.	7/18/17: Testing with COTS (same cells as LLB but different packaging) with EP; effort is collaborative with SAFER team. Have alternate battery designs from ER and AMPS. 12/18: 2018 Phase I SBIR awarded for safe, high energy space suit batteries. The proposed system is an ionic liquid-based hybrid electrolyte system. Estimated Closure duration 3-5 years.
T	Enabling	Heat Rejection for Vacuum and Non-vacuum Applications	Need heat rejection compatible with vacuum and Martian environment. The current state of the art is the Spacesuit Water Membrane Evaporator (SWME) with degraded performance under Martian conditions. LiCl radiators that capture the H2O vapor from the SWME provide a potential solution. A boost compressor on the SWME vapor outlet could potentially yield improved cooling.	12/18: An SBIR contract to develop the Lithium Chloride Absorber Radiator (LCAR) was completed in 2017 but the technology feasibility was not demonstrated. An ICES paper describing the work was published (https://ttu-ir.tdl.org/handle/2346/73073). Estimated closure duration 3-5 years.
T	Enhancing	Multi-gas Monitoring	Need a system to measure/monitor O2, CO2, H2O, NH3, CO, CH2O, CH3SH, etc. Measuring trace contaminants becomes more necessary if a pressure or temperature swing adsorption continuous removal approach for trace contaminants is implemented in an EVA system. This system would replace the traditional activated charcoal cartridge from the list of logistics items but would require measurement of system performance beyond user detection of odor.	7/18/17: JPL and Vista Photonics are doing a combustion products monitoring project for Orion and it could potentially be tuned to other compounds but it has not been expressly investigated for our applications. 12/18: A Phase I SBIR was awarded in 2018 for multi-gas monitoring using chemical sensitive field effect transistors. Intelligent Optical systems has a Phase III for luminesce sensors for pO2, pCO2, relative humidity, temperature, and pressure in a compact package.
D	Enabling	Dust-tolerant Quick Disconnects	Need low mating force, small, dust tolerant quick disconnects that improve on the current state of the art, the EMU Service and Cooling Umbilical (SCU). Fluids include (2) 3750 psia oxygen ports, (3) 35 psi water, (1) 80pin electrical connection with a mandate that the connections be capable of mating/demating under all pressure combinations.	7/18/17: Quick disconnect meeting fluid interface requirements is under development as part of xEMU Lite project. Dust tolerance is a goal of that effort but not actively being worked or required to meet needs of DTO (enhancing capability).
T	Enhancing	Oxygen Pressure Sensor	Need a pressure sensor which is small form factor, high reliability, radiation hardened, and low power consumption.	7/18/17: Have GP50 sensors that can meet minimal requirements but improved performance for future missions is desired. 12/18: No current developmental work.
D	Enabling	5th Percentile Crewmember Fit	Need a suit that accommodates fifth percentile crewmember dimensions (minimum) and still accommodates all system required services (purge valve, umbilical services, display/control unit, positive pressure relief valve, etc.).	10/24/2016: A reduced profile display and control unit (DCU) prototype was developed to fit within the chest area of Z-2 (1st percentile female shoulder breadth) that accommodates listed features. A high fidelity version with functional SCU QD will be tested summer 2017 with Z-2. 7/18/17: HUT is being redesigned in-house to better accommodate Z-2 size range (5th percentile shoulder breadth) and be inclusive of fluid line routings. Anticipate next prototype in FY18. 9/12/2018 A limited fleet sizing study is underway for xEMU, but significant further work is required. 11/22/19: xEMU is working toward meeting this requirement. There is an xEMU risk on fleet sizing because sizing has not been verified with hardware fit checks as yet. xEMU is currently not funded to fabricate hardware to cover the full sizing range.

2020 EVA System Maturation Team Gap List

T/D/K	Enabling/ Enhancing	Gap Name	Description	Status
D	Enhancing	CO2 Sensor	Need CO2/O2 sensor which is sized appropriately for inclusion in a PLSS, not susceptible to humidity, has accurate readings in 3 psia to 23 psia range, and has low time between each sample collection and its associated reporting. The sensor should be a common sensor & avionics package used by EVA, ECLSS and others and capable of sensing a variety of gas (e.g. ammonia, CO2, water vapor, O2, etc.).	11/15/2016: Three different CO2 sensor designs are being developed via AES efforts. Two are susceptible to humidity; one is not, but it has a low TRL. The ISS Program has also initiated an effort to develop a drop-in replacement for the EMU sensor using AES technology. Design down select is scheduled for end FY2017. 1. Modified EMU CO2 Sensor - high TRL, can be adapted to Advanced PLSS, susceptible to humidity, can be adapted to sense O2, small form factor 2. Moderate TRL, susceptible to humidity, need separate detector to sense O2 and humidity, form factor not small Intelligent 3. Low TRL, impervious to humidity, can sense multiple gases with one detector, largest form factor of three detectors 7/18/17: ISS DTO project for CO2 sensor down selected requirements to only measure CO2 and water vapor. For these two aspects, there are two sensors at mid-TRL capability. There are no sensors today that meet PLSS requirements and provide measures of all listed chemicals. 9/12/18 A CO2-only sensor was selected for both the EMU CO2 sensor replacement and the xEMU Demo sensor. The system uses a COTS IR source and detector with improvements to condensation mitigation, simplified temperature compensation, power, and latch up recovery. Multigas capability with smaller form factor is still desired for the future.
T	Enhancing	Alternate Suit Ventilation Circulation	Need a vent loop system with an increased head rise over traditional centrifugal fans. The system would ideally needs to yield 7-10 inches of H2O of headrise at 4.3 psia suit and provide flowrates in the vicinity of 4.5-6 ACFM. There is interest in developing ventilation techniques that would move the PLSS away from the current high-speed turbomachinery approach.	7/18/17: Increased vent loop fan performance as described is an enhancing feature desired for Mars surface missions. The PLSS can meet requirements for xEMU with the planned ventilation loop implementation, as tested in PLSS 2.0 and planned for PLSS 2.5 testing. 12/18: No current development other than the primary path xPLSS for the Demo development. Fan 3.0 is expected to provide 4.9 in H20 headrise with a single-stage centrifugal fan optimized for 35,000 rpm and a power draw of 10.2 Watts at 5.3 ACFM and 4.3 psia.
D	Enhancing	EVA Radio	Need a radiation hardened, radio programmable to support high-criticality UHF communication (voice & limited data) while simultaneously transmitting on a second frequency with high data throughput.	7/18/17: Collaborating with EV on radio (Phase II SBIR ends in FY18) 12/18: Phase III was awarded, and is on contract to deliver a DVT version of the system in FY19. The system is planned to be integrated to the xEMU Demo system.
D	Enhancing	Low-mass Bearings	Need high strength to weight ratio pressurized bearings. Improvements made over the stainless-steel bearings on the EMU can significantly reduce the weight. Most promising current candidates are titanium-alloy bearings in combination with coatings to control surface wear.	5/31/2016: Ti bearings were included in the Z-2 construction and will be evaluated, for mobility and wear, through FY17. The scope of weight reduction includes things such as optimization of stress analysis to lean out the designs of composite components and bearing profiles to just meet 2.0 FOS, for example. Obtaining softgoods that have best available function to mass ratio is another aspect of this. From past experience, this usually does not become a funding priority until a program has a launch mass problem. It will happen, so we would really like to get out ahead of it and in the process be able to realize the best possible system level design in parallel. 8/8/17: SBIR Phase II with titanium looks promising; concludes in FY18 9/12/2018: Phase II SBIR titanium bearing development completed, and Phase-III awarded to build DVT-quality hardware prototypes for the shoulder scye and upper arm bearing. Planned infusion to xEMU following completion of Phase III. Advancements should be applicable to the other bearing locations. 11/22/19: Titanium bearings are being included in the xEMU design where able. Challenges remain to meet optimal stiffness/volume/mass combinations.
T	Enhancing	Smart Thermal Control	Need system heat rejection method which eliminates the need for a separate TCV (autocooling). An ideal cooling system would not require user input or active control to maintain the appropriate thermal balance of the system.	7/18/17: Enhancing capability. The current PLSS design incorporates an autocooling control mode that is algorithm driven. The algorithm is analytically derived and should be further refined/validated with HitL testing. 12/18: No new status or development in this technology area. Algorithmic autocooling based on metabolic rate and environmental heat leakage is implemented on the xEMU Demo system. Innovations in this area may be coupled with advances to the liquid cooling garment.

2020 EVA System Maturation Team Gap List

T/D/K	Enabling/ Enhancing	Gap Name	Description	Status
T	Enabling	Cut/Puncture Resistant Softgoods	Need cut and puncture resistant softgoods for space suit pressure garment applications for planetary surface environments. Longer cycle lives are required than current materials can provide. Gloves and knees are particularly susceptible to cuts.	11/15/16: HPEG does not address increased cut/puncture resistance, self-healing, moisture removal, or active heating components. Phase II SBIR investigating self-healing materials ends FY18. 7/18/17: Phase II STTR awarded to continue investigating puncture resistance with Shear-thickening fluid enhanced fabrics. 12/18: Phase II STTR for EPG development ongoing, Phase II SBIR in closeout. The developed system was a gel-encapsulated self-healing bladder. A silicone RTV replacement for glove padding was also developed.
T	Enhancing	Heat Rejection w/o Dedicated Feedwater	Need EVA System heat rejection method that does not require a dedicated feed water supply (i.e. runs off of cooling loop water). This has the potential of significantly simplifying the thermal control system of the PLSS.	7/18/17: Enhancing capability to reduce consumables usage and on-back mass. 12/18: No new status or development on this technology area.
T	Enhancing	Non-venting Heat Rejection	Need heat rejection to function without venting into the local environment. Non-venting heat rejection could improve consumables usage compared to current technology and also reduce microbial contamination of the surrounding environment in areas where planetary protection is important.	7/18/17: Capability is expected to be required for Mars surface stays. Potential technologies could include further development of the SEAR, which combines a lithium chloride absorber radiator with the existing SWME radiator. 8/12: See "Heat Rejection for Vacuum and Non-vacuum Applications" gap for an update on the LCAR system. No EVA suit heat rejection system not based on the SWME architecture is currently in development.
T	Enhancing	Suitport System Concept Development	Need development of suitport-style concepts for planetary EVAs from vehicles or Habitats. The NASA suitport concept was developed around a rear-entry suit concept with a rigid Suit Interface Plate (SIP).	12/18: The current xEMU DEMO architecture is not built around the suitport concept and would require substantial redesign to accommodate. The suitport architecture should be explored and developed outside the xEMU primary path. Potential topics for initial research or collaboration might include: 1. Hatch opening mechanism (hinges, lock/unlock, and self-don/doff), 2. Elegant integration of SIP (permanent or removable), 3. Build vibration model for suits dangling off suitport, or 4. Elegant solutions for heat sink on SIP.
D	Enhancing	Thermostat Glove Heater Control	Need a glove heater system that can automatically maintain safe operating temperatures in the suit glove. An automatic thermostat controlled system could optimize power draw and eliminate the bulky user control in the suit gauntlet area.	12/18: No work initiated. Current EMU system uses an on-off pull tab actuated switch in the glove gauntlet to active the fingertip heater elements.
T	Enhancing	Anti-microbial/anti-fungal bladder materials	Need material for use within the TCU, bladder, and LCVG that is antimicrobial, antifungal, non-toxic, and O2 compatible. (NASA-STD-3001v2: 4.5.2-4)	5/31/2016: CSSS began to address this gap as part of their LVCG development effort but the status of that effort is unknown. Internal testing was conducted in 2010 and is documented in CTSD-CX-0120.
T	Enhancing	EVA Glove Mobility and Durability	Current gloves result in approx. 75% loss of functional performance (combined strength and mobility) upon donning and pressurizing. Gloves have the shortest effective use life of all EVA pressure garment components, mostly due to the severity of sharp and abrasive hazards found on EVA external interfaces. Glove Thermal Micrometeoroid Garments (TMG) are the first pressure garment components to wear out and must be frequently replaced on the ISS.	11/15/2016: Two new gas pressurized glove prototypes were delivered under the HPEG project in FY16. The gloves are being evaluated in the glovebox at for mobility at 0, 4.3, and 8.0 psid using the HPEG Glove Mobility Protocol. Test results expected to be published Sept, 2017. 9/12/2018: HPEG results published, EMU phase VI is planning an upgrade that incorporates some of the recommended changes.
K		Quantifying Suited Mobility	A consistent and validated methodology does not exist to assess the mobility of a space suit system at the integrated level- neither for benchmarking comparisons nor for requirements verification.	11/15/16: The PGS team, in collaboration with HRP, are investigating new concepts in suited human performance (energy-mobility and EVA benchmarking), which show promise but will require further development as part of HRP funded effort in FY16-18. Still require better methodologies to decompose suited human performance requirement to component-level design. We have good data on single-axis joints and bearings, but complex mobility elements pose challenges. 9/12/2018: HRP EVA benchmarking reduced scope to focus on micro-g environments. Results pending.
K	Enabling	External Environments Handbook	Need properties of dust environment at each destination. Need a NASA-endorsed handbook that describes dust environment for each destination. Need definition of each destination's environmental hazards, including dust constituents. What is the chemical composition of the dust and its characteristics, to include particle size and shapes? Do the properties change when exposed to a habitable environment (pressure, humidity, etc.)? Need radiation environments definition at all locations; unknown material degradation due to radiation beyond LEO; this applies to softgoods, hardgoods, and electronics.	10/12/2016: The EVA Office is attempting to populate and baseline an environments standard for community review and buy-in. Initial draft and ToC available. CSSS completed TDS #1139, System Level Radiation Requirements Analysis which includes cis-lunar and mars radiation environments. CxP DSNE describes lunar environment with some limited maturity; document not finalized. Both AES EVA and CSSS have draft environment spec books that have been compiled from agency resources. Neither book is complete, nor endorsed. Neither project has significant resources available to finalize the books. 9/12/18 Significant work is still required, DSNE is largely unpopulated for these topics.

2020 EVA System Maturation Team Gap List

T/D/K	Enabling/ Enhancing	Gap Name	Description	Status
T	Enabling	Mars Environment Thermal Insulation	Need pressure garments with insulation suited for wider range thermal environments, particularly in the Martian atmosphere environment where vacuum MLI is not effective.	11/15/16: HPEG has Aerogel and hybridshield materials have been incorporated into the prototypes to improve thermal performance. Thermal testing of the layups is current underway (report end of FY17). 12/18: No new status, significant development required to achieve adequate thermal performance without sacrificing mobility.
T	Enhancing	Scratch Resistant Visor System	Need visor that can be on-orbit maintained and potentially repaired and reused after use in an abrasive or dusty environment.	5/30/16: Z-2 was delivered with a protective visor that is capable of rapid R&R 7/18/17: Add reference to prior SBIR P1 report and NCSU student report. This capability would be enhancing for ISS and DSG. 12/18: Z-2.5 Incorporates a scratch resistant coating, testing is underway. This system is not expected to be the ultimate solution.
T	Enhancing	Reusable Drink Bag	Need a reusable drink bag that is not susceptible to biological build-up and that requires limited maintenance between EVA uses, to decrease the amount of logistics during long duration missions. Solutions could include multi-use, cleanable, or extremely light/cheap disposable options.	ISS DIDB is disposable, not infinitely reusable. Prior to implementation of the DIDB, the EMU utilized a reusable drink bag. This system worked well for Shuttle missions with short durations between EVAs. However, due to drying and cleaning issues, this was not a practical solution for space station. However trade space could be reopened to meet needs without new tech (just fly more DIDBs). 12/18: There has been no new work or updates in this technology area.
K	Enabling	Martian Dust/Regolith Properties	Will dust that is built up on outer layer of the suit affect thermal capabilities? Need properties of dust and dust storms at each destination to inform dust resistance requirements for visor. Will one scratch resistant solution work for all destinations? What type of Mars particulates exist? Are they corrosive to filters? Need to know chemical and physical properties of the dust. Mars soil is known to contain perchlorates which may have adverse effects on materials used in space suit construction, notably stainless steel and potentially softgoods.	12/10/2019: No new status
D		Seasonably Variable TMG	Need appropriate TMG for "seasonal" thermal environment changes over course of long duration Mars surface mission with quick changeout features at suit interface.	11/15/16: Aerogel being evaluated within the HPEG effort, co-funded by OCT and AES. FY12/13 testing of prelim material assessed durability and conductive heat transfer. FY14 effort to assess the aerogel thermal insulation as stitched into a prototype glove assembly. Thermal evaluation of prototype assembly effort ceased due to inability to develop an effective test method. FY16 testing of prototype glove layups continues.
D	Enhancing	Cooling Garment	Need cooling garment with improved UA over Shuttle version (SotA). Improve the UA such that warmer water can be used to sink the waste heat from the human and hence reduce the evaporator size or potential need for boost compressor/radiator. Drastically alter the human to cooling loop interfaces such as a fluid filled suit with pumped directly cooled water.	11/15/2016: CSSS RL-LCVG was tested as part of PLSS 2.0 HITL testing but did not show improvement in cooling efficiency over the EMU LCVG. 7/18/17: For primary cooling, the current LCVG is sufficient. Improved UA would be enhancing from PLSS thermal loop power and reliability perspective, but is not required. A secondary LCG cooling loop is required to meet xEMU-Lite design requirements for abort return capability. HITL testing of the CSSS concept demonstrated adequate cooling but design improvements with respect to PGS interfaces and crew comfort are warranted. 12/18: Awarded a 2018 Phase I SBIR to investigate ways cooling garments could be optimized.
K	Enhancing	Defining Suit-Human Interactions	Need an in-suit ground sensor package to provide data on human-to-suit interactions and therefore, improve the ability to design suits which are less likely to injure suit occupants. Specifically desire to understand the ergonomic implications of exploration space suit architectures, notably rear-entry, waist belt, shoulder straps, PLSS interface, and indexing of the suit to the person (sizing, padding, etc.).	5/31/2016: Current scope does not include assessment by an ergonomist to assess Z-2 during analog operations (ARGOS, rock pile) with geology and other exploration tasks. 8/8/17: HRP has funded MIT to evaluate "shoulder injury" and injury countermeasures specifically from 2014-2017. 12/18: Requires update on H3PO work in this area.
T	Enhancing	Disposable/Non-Reusable EVA Suit Concept	Need concepts for reduced-capability, non-reusable EVA systems to trade against the current high-performance modular system.	12/18: awarded a 2018 Phase I SBIR to develop a low-cost, non-reusable PLSS concept.
K	Enhancing	EVA Crew Required Capabilities	The physiological and cognitive performance capabilities that will be required of crewmembers during exploration EVA are not adequately understood. This is a human health and performance gap shared by the Crew Health and Performance SMT and Human Research Program with additional documentation at https://humanresearchroadmap.nasa.gov/Gaps/gap.aspx?i=303.	12/10/2019: No new status
K	Enhancing	EVA Suit Design for Human Health & Performance	The effects of suit design parameters on crew health and performance (physical and cognitive) during exploration EVA are not adequately understood. This is a human health and performance gap shared by the Crew Health and Performance SMT and Human Research Program with	12/10/2019: No new status

T/D/K	Enabling/ Enhancing	Gap Name	Description	Status
			additional documentation at https://humanresearchroadmap.nasa.gov/Gaps/gap.aspx?i=304 .	
K	Enhancing	EVA Suit Sizing & Fit	How does EVA suit sizing and fit affect crew health, performance, and injury risk? This is a human health and performance gap shared by the Crew Health and Performance SMT and Human Research Program with additional documentation at https://humanresearchroadmap.nasa.gov/Gaps/gap.aspx?i=653 .	12/10/2019: No new status
K	Enhancing	EVA Physiological Inputs and Outputs	The physiological inputs and outputs associated with EVA operations in exploration environments are not adequately understood. This is a human health and performance gap shared by the Crew Health and Performance SMT and Human Research Program with additional documentation at https://humanresearchroadmap.nasa.gov/Gaps/gap.aspx?i=306 .	12/10/2019: No new status
K	Enhancing	EVA ConOps for Human Health & Performance	The effect on crew health & performance (physical & cognitive) of variations in EVA task design and operations concepts for exploration environments are not adequately understood. This is a human health and performance gap shared by the Crew Health and Performance SMT and Human Research Program with additional documentation at https://humanresearchroadmap.nasa.gov/Gaps/gap.aspx?i=311 .	12/10/2019: No new status
K	Enhancing	EVA Informatics for Health & Performance	The knowledge and use of real-time physiological, system, and operational parameters during EVA operations to improve crew health and performance (physical & cognitive) is not adequately understood. This is a human health and performance gap shared by the Crew Health and Performance SMT and Human Research Program with additional documentation at https://humanresearchroadmap.nasa.gov/Gaps/gap.aspx?i=308 .	12/10/2019: No new status
K	Enhancing	EVA Injury Risk & Mitigation	The risk of crew injury due to exploration EVA operations and methods for mitigating that risk are not adequately understood. This is a human health and performance gap shared by the Crew Health and Performance SMT and Human Research Program with additional documentation at https://humanresearchroadmap.nasa.gov/Gaps/gap.aspx?i=312 .	12/10/2019: No new status
K	Enabling	EVA Exploration Prebreathe	The DCS mitigation strategies and associated impacts on mission timelines, consumables, and the design of EVA and habitat systems for exploration missions are not adequately understood. This is a human health and performance gap shared by the Crew Health and Performance SMT and Human Research Program with additional documentation at https://humanresearchroadmap.nasa.gov/Risks/risk.aspx?i=168 .	12/10/2019: No new status
D	Enhancing	Bio-med sensor	Need a radiation hardened, wearable biomedical system which does not require the crew to shave.	11/15/16: Options were evaluated by CSSS. There should be an engineering report on the topic but it cannot be located at this time. 7/18/17: Enhancing capability for xEMU Lite (can meet requirements with EMU system). No planned work in this area. 9/12/18: Heart rate only is the planned biomed capability for xEMU. Current design is an adapted wireless commercial system that does not require shaving.