EVA System Maturation Team Status

EVA Technology Workshop 2017

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Lead, EVA System Maturation Team

Agenda

- Overview
    - What is the EVA SMT
    - How “gaps” (delta in what we need vs what we have) are identified, tracked, and shared
- Current Context
    - What is driving the priorities by schedule and content
- Subset of Key Technical Gaps by Mission/Destination

EVA System Maturation Team

- NASA HEOMD established System Maturation Teams in Aug 2013 as part of a capability driven approach to future missions
  - **EVA/JSC**
  - Human-Robotic Mission Operations/JSC
  - Crew Health & Performance/JSC
  - Autonomous Mission Operations/ARC
  - Communication & Navigation/KSC
  - ECLSS/HQ
  - Entry, Descent, & Landing/LaRC
  - Power & Energy Storage/GRC
  - Radiation/JSC
  - Thermal (including cryo)/JSC
  - SKG Measurement Instruments & Sensors/HQ
  - Fire Safety/GRC
  - Propulsion/MSFC
  - ISRU/JSC

EVA System Maturation Team

- The capability driven approach (vs new program driven) required that the SMTs understand each possible mission scenario, prioritize the needed technologies, and integrate with other SMTs

- EVA SMT has implemented this for both EVA and Launch/Entry/Abort (LEA) by striving to
  - **Identify**, champion and mature technology as to support, enable, and enhance current and future missions
  - **Prioritize** investments given the current hardware status and mission scope and schedule
  - **Communicate** plans and needs with projects (EMU, OCSS, AdvEVA), stakeholders, and funding sources (SBIR, STMD, etc.)

EVA System Maturation Team

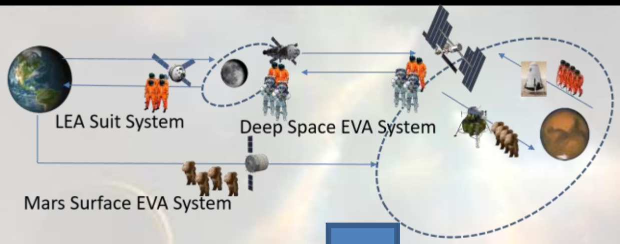
Key participants	
Raul Blanco, lead	
Brian Johnson, deputy	International SMT lead, program integration
Lindsay Aitchison, SEI lead	Mission Architecture Needs
Rob Boyle, ISS EMU SM	EMU history, current flight needs and operational considerations (near term customer)
Dustin Gohmert, Orion Crew Survival System PM/SM	LEA history, Orion flight needs, near term flight implementation, LEA technology implementer (near term customer)
Liana Rodriggs, AdvEVA PM	xEMU technology needs (near term customer)
Ben Greene, AdvEVA SEI lead	xEMU technology needs, requirements implementation
Amy Ross, SSA development team lead	SSA technology implementer
Colin Campbell, PLSS development team lead	PLSS technology implementer

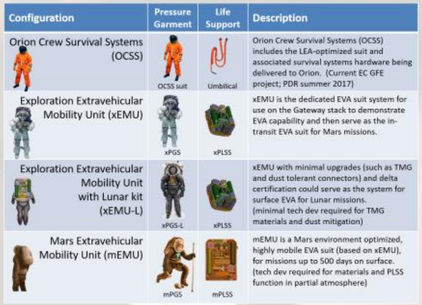
EVA System Maturation Team

- Three types of gaps:
  - **Knowledge**: unknown data or mission parameters that will ultimately drive hardware requirements
  - **Development**: at least one potential solution has been identified but additional work is required to ensure feasibility of the options (TRL 3-5)
  - **Technology**: no known viable solution and new technology must be developed (TRL 0-3)
    - Note: In some cases, the existence of a hardware/technology gap cannot be determined until a preceding knowledge gap is answered

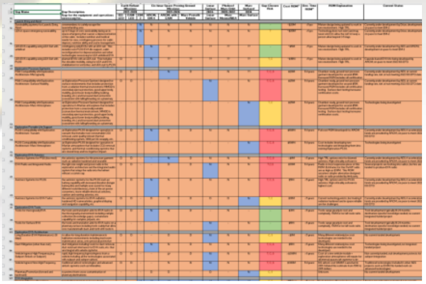
EVA System Maturation Team

- Method
  - Assess as mission changes – “what capability is needed when”
  - Update EVA “Bat” chart – “how many suits to provide the required capabilities and when are they used”
  - Update Suit Arch chart – “what does each suit do and how is it architected”
  - Assess knowledge and technology gaps and need dates (must have technologies ready for implementation by PDR for each suit)
  - Identify appropriate funding sources; examples include:
    - Crowd sourcing (multiple methods) for novel concepts
    - STTR for TRL 1-3 (materials, coatings, and sensors)
    - SBIR for TRL 1-3 (gas sensors, titanium bearings, TCC)
    - STMD for TRL 4-6 (SWME, RCA, HPEG are examples)

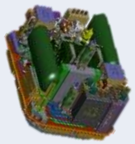
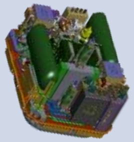




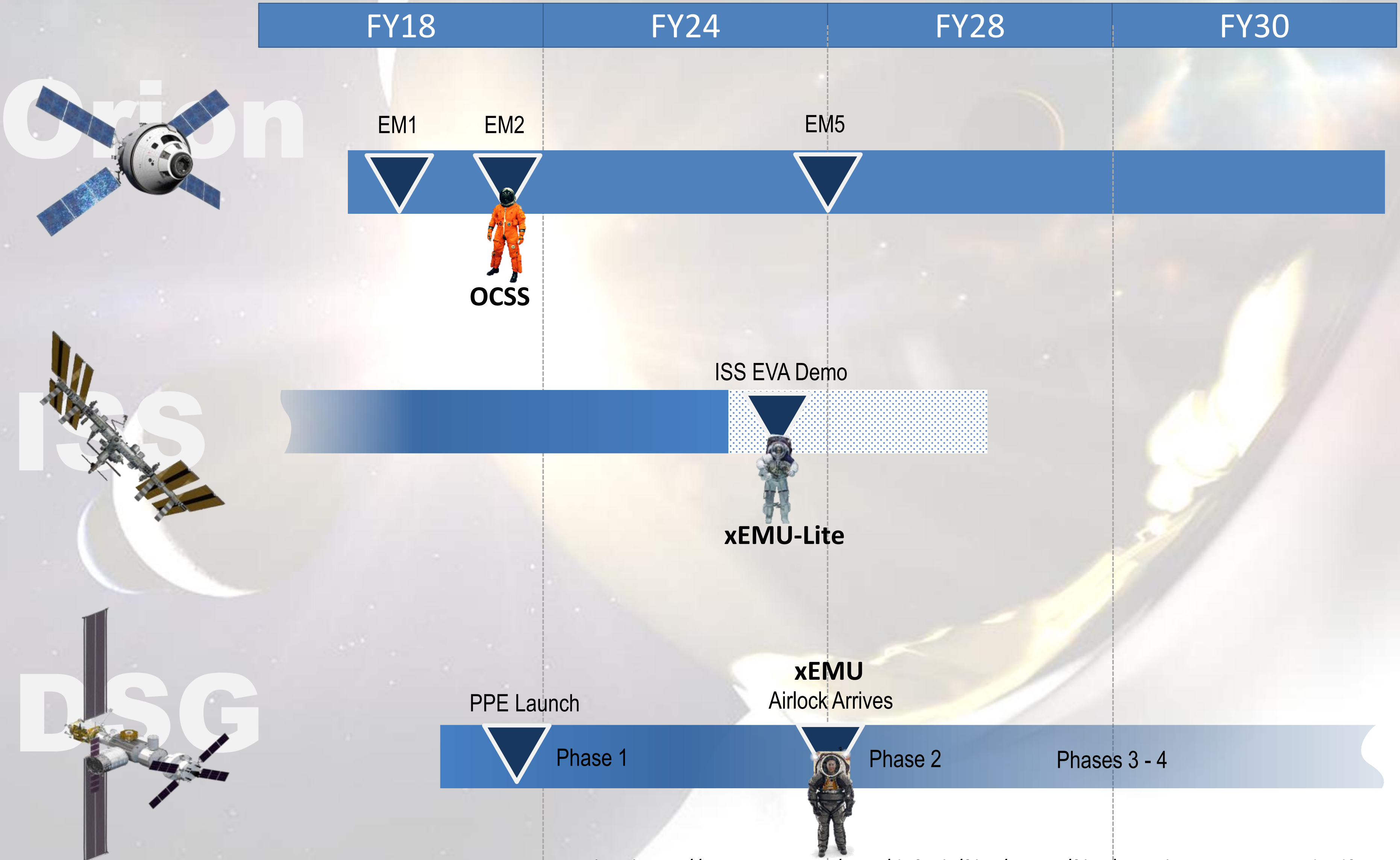
Configuration	Pressure Garment	Life Support	Description
Orion Crew Survival Systems (OCSS)	OCSS suit	Umbilical	Orion Crew Survival Systems (OCSS) includes the LEA-optimized suit and associated survival systems hardware being delivered to Orion. (Current EC GFE project; PDR summer 2017)
Exploration Extravehicular Mobility Unit (xEMU)	xPGS	xPLSS	xEMU is the dedicated EVA suit system for use on the Gateway stack to demonstrate EVA capability and then serve as the in-transit EVA suit for Mars missions.
Exploration Extravehicular Mobility Unit with Lunar kit (xEMU-L)	xPGS-L	xPLSS	xEMU with minimal upgrades (such as TMG and dust tolerant connectors) and delta certification could serve as the system for surface EVA for Lunar missions. (minimal tech dev required for TMG materials and dust mitigation)
Mars Extravehicular Mobility Unit (mEMU)	mPGS	mPLSS	mEMU is a Mars environment optimized, highly mobile EVA suit (based on xEMU), for missions up to 500 days on surface. (tech dev required for materials and PLSS function in partial atmosphere)



Exploration EVA Hardware Architecture

Configuration	Pressure Garment	Life Support	Description
Orion Crew Survival Systems (OCSS) 	 OCSS suit	 Umbilical	Orion Crew Survival Systems (OCSS) includes the LEA-optimized suit and associated survival systems hardware being delivered to **Orion**. (Current EC GFE project; just completed PDR)
Exploration Extravehicular Mobility Unit (xEMU) 	 xPGS	 xPLSS	xEMU is the dedicated EVA suit system for use on the **Gateway** stack to demonstrate EVA capability and then serve as the **in-transit** EVA suit for Mars missions.
xEMU with Lunar kit (if NASA adds this destination) 	 xPGS	 xPLSS	xEMU with minimal upgrades (such as TMG and dust tolerant connectors) and delta certification could serve as the system for **surface** EVA for **Lunar** missions. (minimal tech dev required for TMG materials and dust mitigation)
Mars Extravehicular Mobility Unit (mEMU) 	 mPGS	 mPLSS	mEMU is a **Mars** environment optimized, highly mobile EVA suit (based on xEMU), for missions up to 500 days on **surface**. (tech dev required for materials and PLSS function in partial atmosphere)

Near Term Program Need Dates



FY18 FY24 FY28 FY30

Orion

EM1 EM2 EM5

OCSS

ISS

ISS EVA Demo

xEMU-Lite

DSG

PPE Launch

xEMU
Airlock Arrives

Phase 1

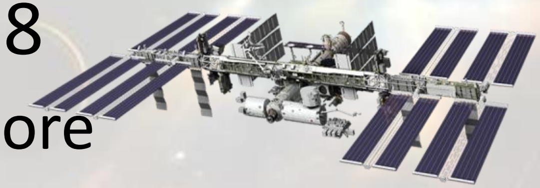
Phase 2

Phases 3 - 4

DSG Plan: https://www.nasa.gov/sites/default/files/atoms/files/nss_chart_v23_tagged.pdf

EMU to ISS EoL

- Assuming that EMU could be asked to continue to support ISS EVAs until 2028
  - Assuming EVA rate similar to today or more
  - Goal is 100% EVA availability (always ready when called)



- Goal for technology investments (priority order)
  1. EMU risk mitigation
  2. EMU enhancements that also mature AdvEVA technologies
  3. EMU as a testbed for AdvEVA technologies

EMU to ISS EoL - Examples

1. EMU risk mitigation
   - Currently engaged in study that should complete end of CY for hardware solutions to reduce EMU water in helmet risk
2. EMU enhancements that also mature AdvEVA technologies
   - CO2 sensor
     - Since 1999, seven in-flight failures have occurred, most likely as a result of condensing moisture in the sense cell
     - Project was initiated to replace the aging sensors with more reliable units while pursuing a design that could also be extensible to the xPLSS
     - ISS and Exploration would benefit if we developed a moisture tolerant CO2 sensor for EMU that could also meet exploration requirements before the current sensors life expires in 2019
       - Key challenges: multi-gas monitoring, increased radiation, operation across a wide range of internal and external gas pressures, long term stability, etc
     - Project concludes with testing of 3 candidate sensors in December 2017 to support ISS downselect decision
       - Leading candidate likely transitioned to flight project phase early next CY

UTAS NDIR Sensor

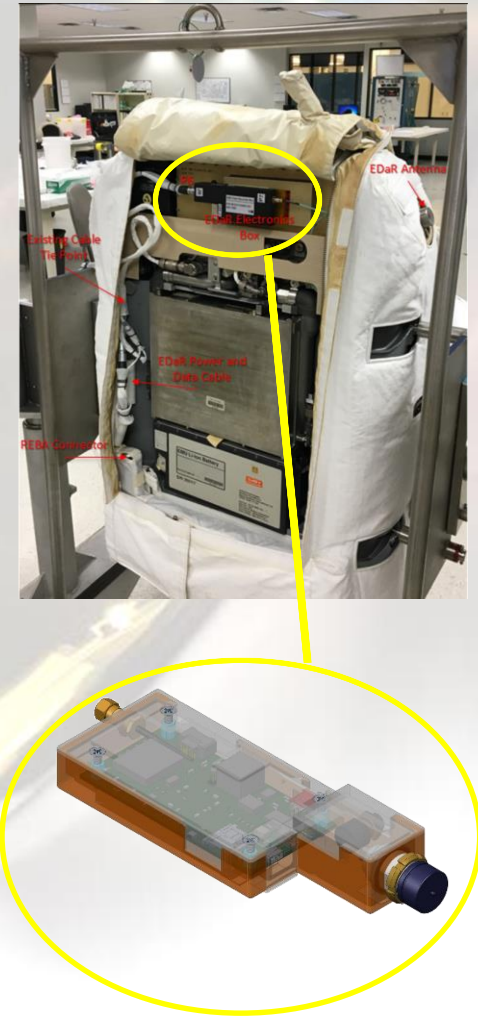
JPL TDL Sensor

Vista Photonics TDL Sensors

EMU to ISS EoL

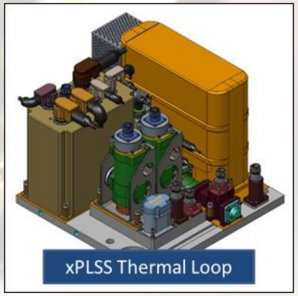
2. EMU enhancements that also mature AdvEVA technologies

- EMU Data Recorder (EDaR)
  - Early fault detection and failure root cause analysis are hampered by lack of available EMU data real-time during EVA and post-EVA
  - No data storage capability on EMU and data transmission via radio is limited by S-band coverage
    - In the default Data Mode COMBO, one data set is transmitted every 2 minutes
    - In Data Mode EMU, one data set is sent every 30 seconds
  - Project was initiated to increase EMU engineering team insight and support troubleshooting activities
    - EDaR will connect to P4 and record the caution and warning data during the EVA
    - Data will be stored locally and can be transmitted over the ISS Internal and External Wi-Fi
    - Option to transfer the stored data manually via USB after the EVA has completed
  - xEMU has similar need for data insight to support troubleshooting on future missions with increased data transfer time
    - EDaR designed for commonality between ISS EMU and xEMU systems
  - Flight units to be delivered next Spring

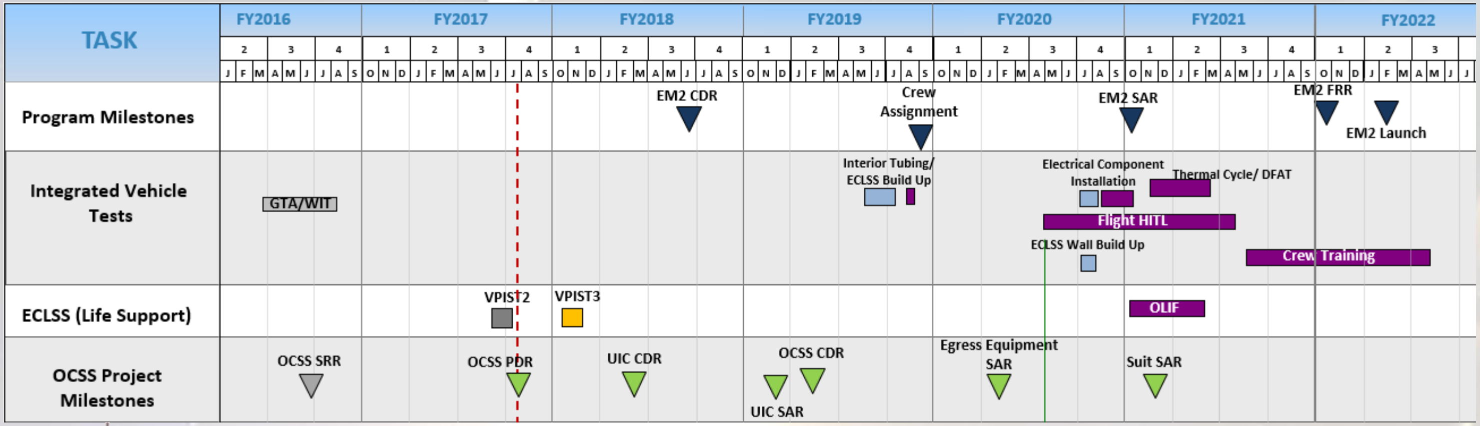


EMU to ISS EoL

3. EMU as a testbed for AdvEVA technologies (or ISS as a testbed)
   - SWME Express Rack Flight Experiment (SERFE)
     - Suit Water Membrane Evaporator (SWME) technology selected for thermal management in xEMU due to longer life and tolerance to degraded water quality
       - SWME use demonstrated through extensive ground testing with PLSS 2.0
       - Previously considered chamber evaluations with SWME in EMU thermal loop as sublimator alternative
     - Demonstrate 25 EVA operational life of SWME in a relevant environment using simulation of complete PLSS thermal loop
       - Up to 8 hour periods of simulated EVA
       - Quiescent periods to simulate down time between EVAs
     - Assess SWME compatibility with ISS systems by evaluating:
       - Flow stagnation
       - Particle migration
       - Potential growth and impact of microbial organisms on SWME and loop component performance (and biocide performance)
       - Long term material degradation and interaction with ISS water in microgravity
       - Tolerance to air in the thermal loop and SWME ability to degas
     - Plan to deliver hardware to ISS end of FY18 for a ≥ 1 year flight experiment



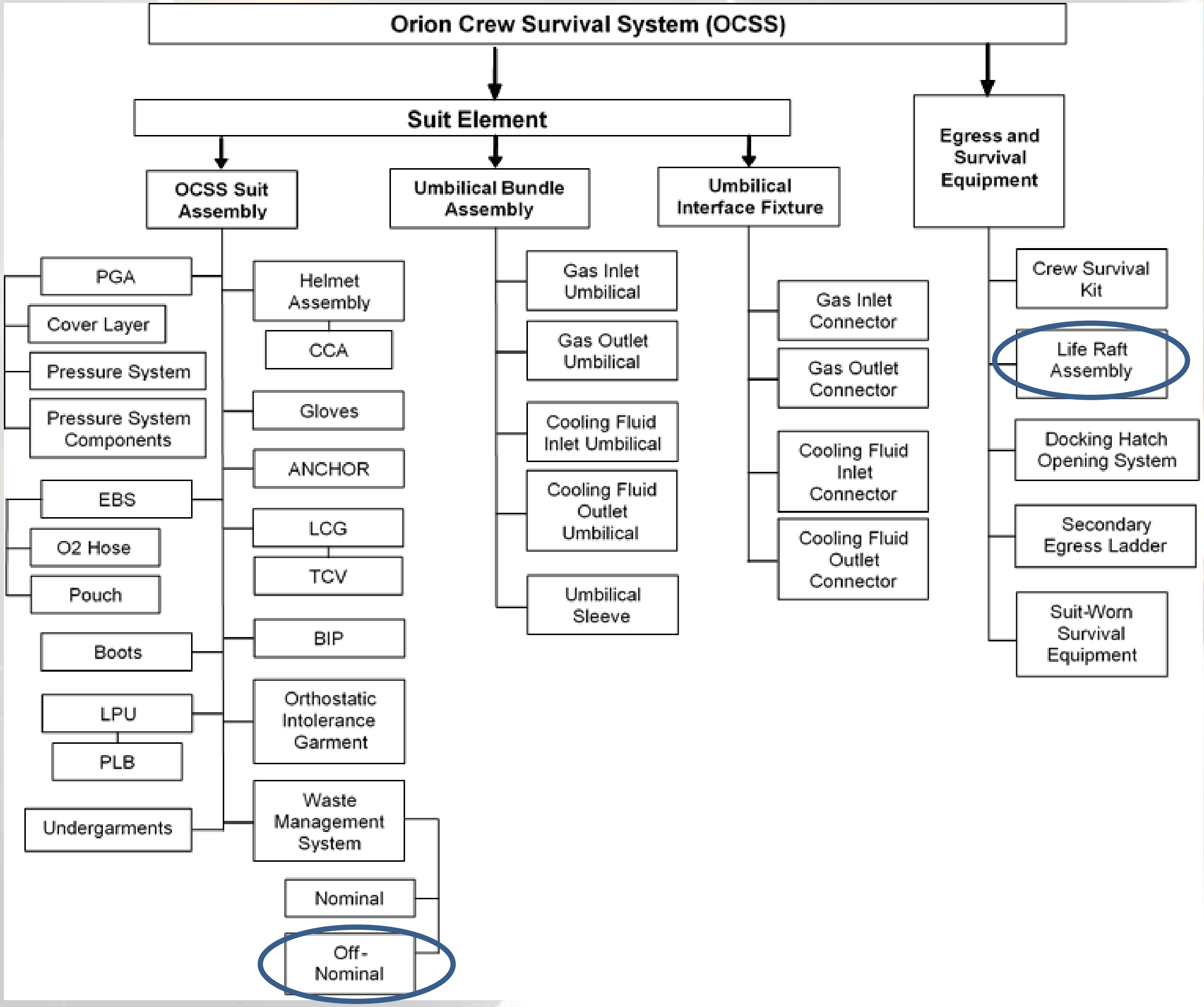
OCSS



- Orion Crew Survival System (OCSS) is a GFE project that will support EM-2 and beyond
- PDR for the system was July 2017
- CDR for the system is planned for early CY19

OCSS

- OCSS Product Breakdown Structure and Identified Gap Areas



OCSS

- OCSS gap status
  - Two risks were identified for development
    - Long duration waste management (enabling)
    - Life raft weight reduction (enhancing)
  - Long Duration Waste Management (enabling)
    - Crowd sourcing (“Space Poop Challenge”) for conceptual methods
    - SBIR for low TRL concept development – H4.02-8817 In-Suit Waste Management Technologies (Omni Measurement Systems, Inc.)
    - Currently contracting for PDR and post PDR concept maturation
    - SMT championing an ISS flight demonstration around CDR
  - Life raft weight reduction (enhancing)
    - SBIR – H4.01-9899 Lightweight, Compact Survival Rafts (Kennon Products, Inc.)
    - Follow on contract

xEMU

- xEMU is the first exploration EVA suit that is assumed to be required in the late 2020s to support deep space microG EVA

xEMU Lite
ISS Demonstration

xEMU Lite	Feature	xEMU
4.3 psi	**Operating Pressure**	8.2 psi
LEO Microgravity	**Design Environment**	Deep Space Microgravity Surface
Upper Torso + Min. Lower Torso	**Mobility**	Upper Torso + Full Lower Torso
Scarred for future upgrade	**Crew Autonomy**	Graphical Display

xEMU
Deep Space EVA
For
Gateway and Mars Transit

Cis-Lunar/Deep Space Gateway Minimum Capabilities (in review)

Parameter	xEMU Lite	xEMU
Gross Mobility	Upper Body	**Upper Body Minimum, Full** Body desired
Operational Pressure	0-4.3 psi	0-**8.2** psi
Dust/Dirt	None	None
MMOD	Primary Impacts	Negligible
Crew EVA Autonomy	Emergency Response; Consumables Tracking; Self-alerts	Emergency Response; Consumables Tracking; Self-alerts, **Informatics**
Quiescent Stowage Prior 1st Use	12 mo	24 mo
Operational Life	100 hr	**624** hr
Operational Cycle Life	10 EVAs	**78** EVAs
Separation from Structure	Double-tether	Double-tether

Key Cis-Lunar Gaps

- High Strength-to-Mass Ratio Components (Enhancing; Enabling for surface)
  - Need mass/stress-optimized structures for PGS upper torso, bearings, and brief to bring PGS mass below 150 lb
  - Previously evaluated chopped fiber composite bearings, composite upper torso and brief, and titanium bearings
- EVA Gloves (Enhancing)
  - Current gloves result in approximately 75% loss of functional performance (combined strength and mobility) upon donning and pressurizing
  - High Performance EVA Glove (HPEG) testing has identified high humidity in gloves as key contributor to hand injury
  - Two new gas pressurized glove prototypes 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 Fall 2017.
- Low-Consumable Trace Contaminant Removal (Enhancing)
  - 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.

Key Cis-Lunar Gaps

- Graphical Display and Input Device (Enabling)
  - Need a radiation tolerant graphical display that is compatible with the suit (either 100% O2 compatible and inside the PGS -OR- compatible with the helmet & visors) and operable by the suited crewmember.
- PLSS Batteries (Enhancing)
  - Need a safe, high-energy density power sources that are rechargeable post-EVA. 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
- Dust Tolerant Mechanisms (Enabling for surface)
  - Need bearings and mechanisms (relief valves, purge valves, disconnects, rear entry hatch, actuators, etc) that function after being exposed to direct dust and/or that are easily maintained during a mission
- Active Tintable Electronic Visor Coating (Enhancing)
  - Need to incorporate active tintable electronic coating technologies such as electrochromics or variable solar reflectance into a polycarbonate helmet

Lunar Surface Minimum Capabilities **(Notional)**

Parameter	**xEMU**	**xEMU Lunar***
Gross Mobility	**Upper Body Minimum,** Full Body desired	**Full** Body required
Operational Pressure	0-8.2 psi	0-8.2 psi
Environment	• Dirt/dust – None • Vacuum • Temp – Cis Lunar • Plasma – Yes • MMOD - Negligible • Planetary Protection Risk - No	• **Dirt/dust** – Fine, abrasive particles • Vacuum • **Temp** - Lunar Surface • Plasma – Yes • MMOD - **Secondary** • Planetary Protection Risk - No
Crew EVA Autonomy	Emergency Response; Consumables Tracking; Self-alerts, Informatics	Emergency Response; Consumables Tracking; Self-alerts; **Navigation, Timelines, Procedures, Buddy Status, Vehicle Status**
Quiescent Stowage Prior 1st Use	24 mo	24 mo
Operational Life	624 hr	624 hr
Operational Cycle Life	78 EVAs	78 EVAs

* The Lunar capabilities are for an envisioned Lunar surface upgrade to the xEMU IF the agency were to move focus to that mission. As this is not the agency plan, this configuration is not currently being pursued for maturation

Key Lunar Surface Gaps

- Environmental Protection Garment (Enabling)
  - Need dust tolerant and maintainable/cleanable fabric and suit integration mechanism with thermal protection sufficient for vacuum thermal environment.
    - Previous testing has shown advantages to coated fabrics with bonded seams at preventing dust migration but coatings failed early in presence of abrasive lunar regolith
  - Also need refined methodology for assessing abrasion resistance of materials and dust migration through EPG.
- Surface Optimized Space Suit Boots (Enabling)
  - Need boots compatible with mobility (ankle and mid-foot) required for walking in gravity environments that maintain stability on loose and uneven terrain, can be adjusted at pressure to improve fit during EVA, provide proper insulation from conductive ground contact (+/- 250F), durable for abrasive dirt and dust environment, and comfortable for multi-hour wear
  - Previous boot iterations have highlighted ankle transition as key design problem: need volume to don/doff boot but also provide stability to prevent heel slip and blisters during active use

Mars Surface
Minimum Capabilities **(Notional)**

Parameter	xEMU	xEMU Lunar	mEMU
Gross Mobility	Upper Body	Full Body	Full Body
Operational Pressure	0-8.2 psi	0-8.2 psi	0-8.2 psi
Environment	• Dirt/dust – None • Vacuum • Temp – Cis Lunar • Plasma – Yes • MMOD - Negligible • Planetary Protection Risk - No	• Fine, Dirt/dust – Fine, abrasive particles • Vacuum • Temp – Lunar Surface • Plasma – Yes • MMOD - Secondary • Planetary Protection Risk - No	• Dirt/dust – **Larger, chemically reactive particles** • **Partial atmosphere** • Temp – **Seasonal** • Plasma – No • MMOD - **Negligible** • Planetary Protection Risk - **Yes**
Crew EVA Autonomy	Emergency Response; Consumables Tracking; Self-alerts	Emergency Response; Consumables Tracking; Self-alerts; Navigation, Timelines, Procedures, Buddy Status, Vehicle Status	Emergency Response; Consumables Tracking; Self-alerts; Navigation, Timelines, Procedures, Buddy Status, Vehicle Status
Quiescent Stowage Prior 1st Use	24 mo	24 mo	24 mo
Operational Life	624 hr	624 hr	624 hr
Operational Cycle Life	78 EVAs	78 EVAs	78 EVAs

Key Mars Surface Gaps

- Environmental Protection Garment (Enabling)
  - Need dust tolerant and maintainable/cleanable fabric and suit integration mechanism with more thermal protection for non-vacuum thermal environment.
    - If robust design is not feasible, consider low mass, low volume solutions that are easily replaced insitu
  - HPEG has Aerogel and hybridshield (NanoSonic) materials have been incorporated into the prototypes to improve thermal performance. Thermal testing of the layups is current underway (report end of FY17).
- Non-vacuum Continuous CO2/RH Removal (Enabling)
  - Need continuous CO2/RH removal capability that can operate within the vacuum and Martian atmospheres
  - Specific areas of interest include:
    - a. Update/supersede amine state of the art
      - i. Improvements in amine uptake
      - ii. Alternative processes such as temperature swing adsorption, selective permeable membranes, etc.
    - b. Augment amine operation using thermal swing adsorption approach
    - c. Augment amine operating using boost compressor to enable pressure swing operation in the Martian atmosphere
- Dust Tolerant Mechanisms (Enabling)
  - Need protection of bearings, relief valves, purge valves, disconnects, rear entry hatch, actuators and other mechanisms to preclude dust from hampering motion / function over operational life on Martian surface
  - Soil constituent parts are dissimilar to lunar soil in both physical and chemical properties

Key Mars Surface Gaps

- Heat Rejection for Vacuum and Non-vacuum Applications (Enhancing)
  - 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 H_2O vapor from the SWME provide a potential solution. A boost compressor on the SWME vapor outlet could potentially yield improved cooling.
- Bio-med sensor (Enabling)
  - Need a radiation hardened, wearable biomedical system which does not require the crew to shave that provides heart rate and rhythm data, at a minimum
  - Must be compatible with 100% oxygen environment
- Multi-gas Monitoring (Enhancing)
  - Need a system to measure/monitor (O_2, CO_2, H_2O), (NH_3, CO, CH_2O, CH_3SH), etc.
  - Measuring of the trace contaminants becomes more necessary with a pressure or temperature swing adsorption continuous removal approach for trace contaminants as it would remove the traditional activated charcoal cartridge from the list of logistics items but would require some level of validation that the function was operating beyond the human nose.
- Anti-microbial/anti-fungal bladder materials (Enhancing)
  - Need material for use within the TCU, bladder, and LCVG that is antimicrobial, antifungal, non-toxic, and O_2 compatible.
  - Testing of candidate materials was conducted in 2010 and is documented in CTSD-CX-0120.

Conclusion

- The EVA SMT maintains an awareness of changing program needs and priorities and then makes updates to the gap list and priorities accordingly
- These priorities are then exercised when communicating and championing work from
  - Crowdsourcing
  - JSC and EA IRD
  - Space Act Agreements
  - SBIR/STTR
  - STMD projects
  - ISS GFE projects
- This forum and possibly ICES will be used as a regular means of communicating this information

BACK UP

Key Knowledge Gaps

- Develop Scalable EVA Impact Model
  - Need to develop and validate a scaleable (something that could be applied to Moon and Mars) impact requirement and associated verification method for falls on planetary surfaces.
  - Two separate impact requirement approaches were investigated during the Z-2 suit developmet activity. The pros/cons of applied requirements and methodology were documented in a 2016 ICES paper.
- Dust Cleaning/ Maintenance for internal habitable volume
  - Need programmatic requirement for levels of contaminate within the habitable volume.
  - Based on suit outer garment material, dust properties, and vehicle architecture what type of pre-ingress cleaning methods and tools will be required to remove dust from suit?
- Define 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.).
- Quantify 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.
  - 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.