55th International Conference on Environmental Systems
12-16 July 2026, Rio Grande, Puerto Rico
ICES-2026-126

Mars Portable Life Support System Status and Plan

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Introduction

- A new development effort for a Mars Exploration Extravehicular Mobility Unit (MxEMU) has started with the Mars Portable Life Support System (PLSS)
- The MxEMU will build off the existing government reference design, the Exploration Extravehicular Mobility Unit (xEMU)
- The environment on Mars will present a unique challenge:
  - Carbon dioxide atmosphere: 0.15psia
  - 3/8th gravity field (2.2x Lunar gravity)
  - Cold atmospheric temperatures: (down to - 143°C (130°K))
  - Extended mission profile and long quiescent period for transit
- Each environmental consideration presents a new challenge for a Mars suit which will require a testbed and analysis to consider options

Historical Suit Design - Apollo

- The Apollo Suit had a Pressure Garment Assembly (PGA), a Portable Life Support System (PLSS), and a separate Oxygen Purge System (OPS)
  - PGA is similar to the modern Pressure Garment System (PGS), the OPS is now included in the PLSS package
  - The suit used a Liquid Cooling Garment (LCG) for cooling the crewmember
  - The suit doubled as the Intravehicular Activity (IVA) suit
- The PGA was made up of a neoprene coated nylon bladder with convoluted joints, a nylon restraint layer, and a Thermal Micrometeoroid Garment (TMG) that included an inner and outer shell of Bata cloth, seven layers of aluminized Kapton film separated by six layers of Beta Marquisette, and a liner of two layers of neoprene-coated nylon ripstop
  - The apollo PGA was custom for each crewmember
- The PLSS used a passive porous plate sublimator for cooling, Lithium Hydroxide (LiOH) for CO_2 removal, and 100% oxygen at 3.6psia during EVA
- The OPS provide 30 minutes of emergency oxygen flow in case of failure 3.63 kg/hr
- A Buddy Life Support System (BLSS) was used for backup cooling and would connect a failed suits LCG to their “buddy” nearby



Apollo Space Suit

Historical Suit Design - EMU

- The EMU was used for the Shuttle and is used on the International Space Station (ISS)
- It advanced the suit design from Apollo to be a singular modular architecture
  - PLSS and OPS were combined
  - Tightly packaged PLSS to be able to fit through the airlock
  - The suit provided EVA capability only, not IVA
  - A Hard Upper Torso (HUT) was added to improve upper body mobility
  - A Display and Control Module (DCM) to display oxygen, power, water, comms was added
  - A single Service and Cooling Umbilical (SCU) was added to simplify recharging of all consumables
  - Lower body mobility was deemphasized – no lunar walking – to reduce mass
- A modular architecture allowed for a variety of astronaut sizes, easier maintainability, safer serviceability, improved caution and warning, less complex emergency O2 systems, and a reusable system
- The EMU has been running for 40+ years and has included numerous improvements over its life
  - Planar fiberglass HUTs with serviceable ducts
  - Orbit Replaceable Units (ORUs)
  - Refined Liquid Cooling and Ventilation Garment (LCVG) water/vent networks
  - Space-to-Space Extravehicular Mobility Radio (SSER) Ultra High Frequency (UHF) radios,
  - DCM controls for fans, water, and communications.
  - Used LiOH at the onset and then switched to regenerable MetOx



EMU Space Suit

Government Reference Design - xEMU

- The xEMU is a significant evolution from the EMU and is being used as a government reference design for commercial vendors such as Axiom Space
- xEMU is EVA only and incorporates numerous improvements
  - Modular components and increased autonomous control
  - Increased 8-hours performance, 100+ EVA per mission
  - Regenerable CO2 removal using Rapid Cycle Amine (RCA) swing beds – replaces MetOX and regenerates actively during EVA
  - Motor Controlled Variable Pressure Regulators
  - Spacesuit Water Membrane Evaporator (SWME) – replaced sublimator for cooling and decouples the ventilation and thermal loops, providing more reliability and contamination tolerance
  - Secondary Oxygen reduced to 3000psia to match primary pressure, compared to shuttle/Apollo 6000 psia for safety and simplifying recharge
  - Auxiliary thermal control loop for backup cooling
  - Lower body mobility



xEMU Space Suit

Umbilical Suit EVA

- Umbilical suits represent early and evolving approach to EVA prior to the implementation of a PLSS
- Many previous missions used umbilical suits
  - Gemini used umbilical to provide oxygen and cooling in an “open loop” – exhaled gas was vented to space
  - Skylab used Apollo A7LB suit but used an umbilical instead of a PLSS to provide oxygen, cooling, communications, and monitoring
  - SpaceX used umbilical to provide life support during their Polaris Dawn mission
- Umbilical suits are not the preferred option for Mars, though represent a “fall back” in case requirements preclude the use of a PLSS due to mass or other constraints
  - University of Maryland has concepted a “BioBot” to follow the crew member with an umbilical



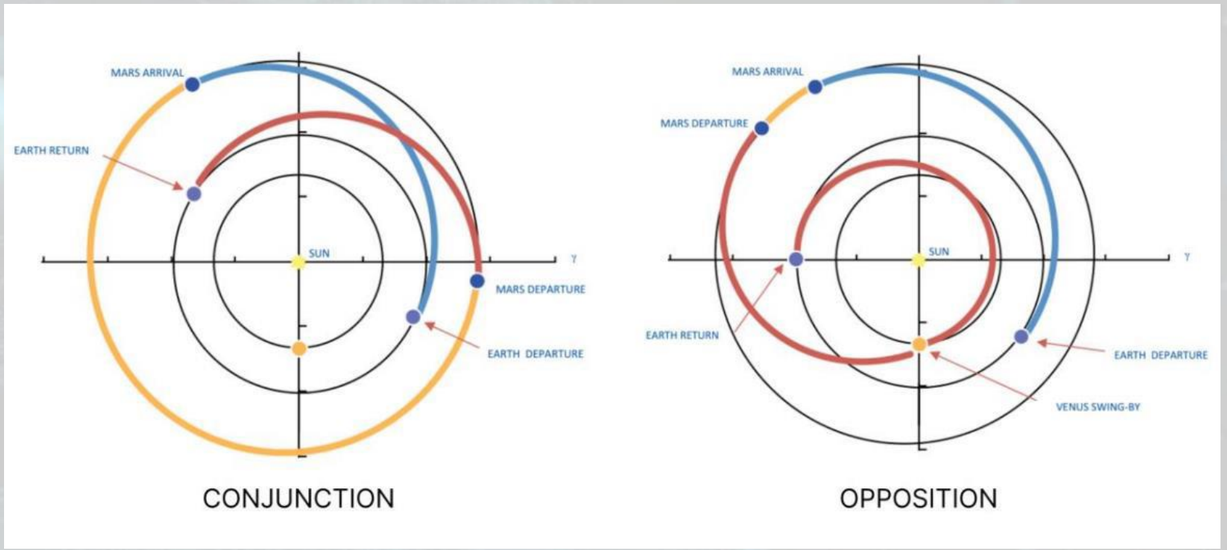
Gemini Space Suit

Mars Mission Architecture

- Mission profile must be considered to understand the number of EVA's and Quiescent time in transit
  - Conjunction of opposition orbits lead to widely variable parameters
- Prior decision memo at NASA favor an opposition mission for the shortest duration mission with the least time on Mars.
  - 305 days to Mars, 50 days in orbit, 30 days on surface, and 375 days return
  - 730 days total
- For both short duration surface stays; preliminary EVA design requirement: 25 EVAs

	Transit "To, From" (days)	Orbit (days)	Surface (days)	Total (days)	Mission EVAs (#)	EVAs Design reqt.
Opposition mission #1	305, 375	50	30	730	20	25
Conjunction mission #2 (short stay)	200, 200	500	30	900	20	25
Conjunction mission #3 (long stay)	429, 429	365	300	1223	125	150+

Mars Reference Missions

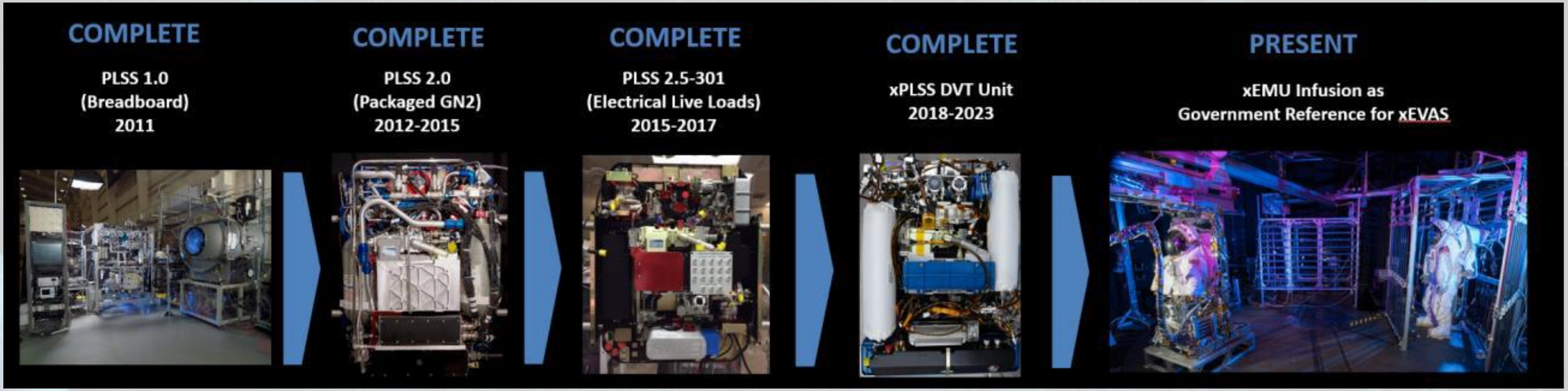


Mars PLSS Planning

- Prior government reference design suit, the exploration EMU (xEMU) took ~15 years to develop
- A breadboard leading to a DVT mars suit is expected to take a similar amount of time.
- Expect to be able to utilize some components from xEMU DVT for Mars

	2026	2027	2028	2029	2030	2031
System Performance Evaluation						
Mars Suit Mass Evaluation						
Prototype Component Dev.						
Mars PLSS Testbed Buildup						
Mars PLSS Testbed Testing						
DVT Component Dev.						
DVT Buildup						Future >

High Level Schedule for Development of a Mars PLSS

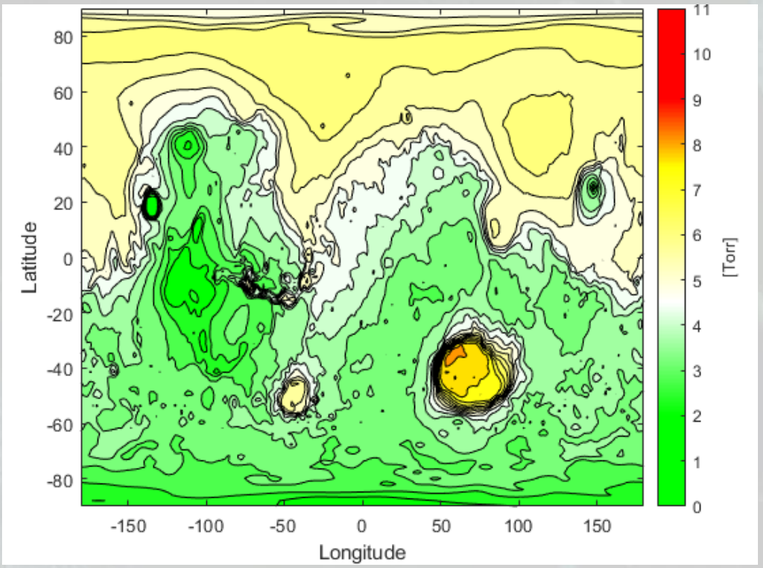


Mars Suit Considerations

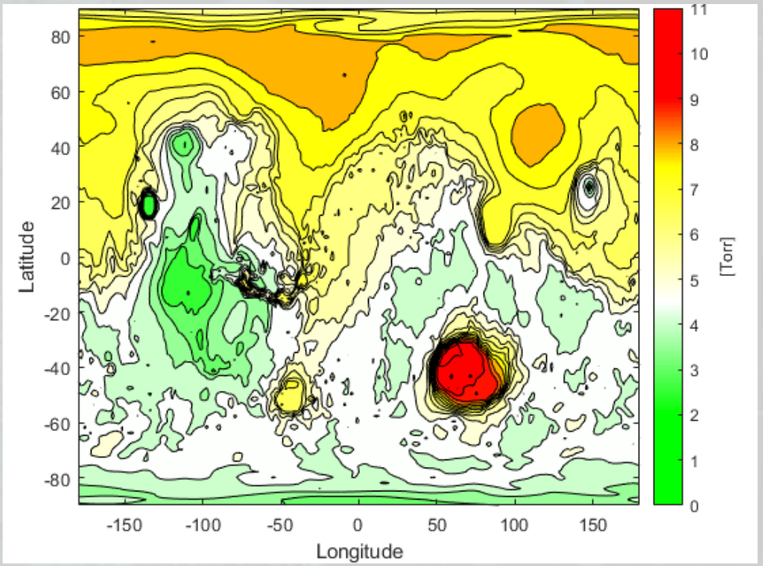
- **Gravity Field**
  - Mars is at 0.38 g, which is 2.3 times that of lunar gravity (0.17 g)
- **Atmosphere**
  - 95% carbon dioxide, average 4.6 torr
  - Further details following
- **Temperature**
  - Ranges from -143°C to 20°C depending on location, season, and time of day
  - Further details following
- **Radiation**
  - Reduced solar irradiance compared to earth, atmosphere provides limited reduction compared to deep space/lunar, further studies required
- **Dust and Soil**
  - Soil is varied depending on landing site
  - Dust is airborne and anticipated between 0 to < 10 µm

Pressure Environment - Mars

- Pressure environments range from 0.2 torr to 9 torr
- Pressure maps represent lowest and highest pressures on Mars depending on the time of year (Summer/Winter)
  - Pressure is the lowest typically during Northern Summer/Southern Winter and highest typically during Northern Autumn and Winter/Southern Spring and Summer
  - CO2 will condensate in the polar caps in the winter and sublimate in the spring, driving the pressure up and down
- Pressure environment generally excludes Hellas Planitia crater (in red) (>7torr)
  - This pressure boundary is included to assist with having PLSS systems that rely on vacuum to operate on Mars



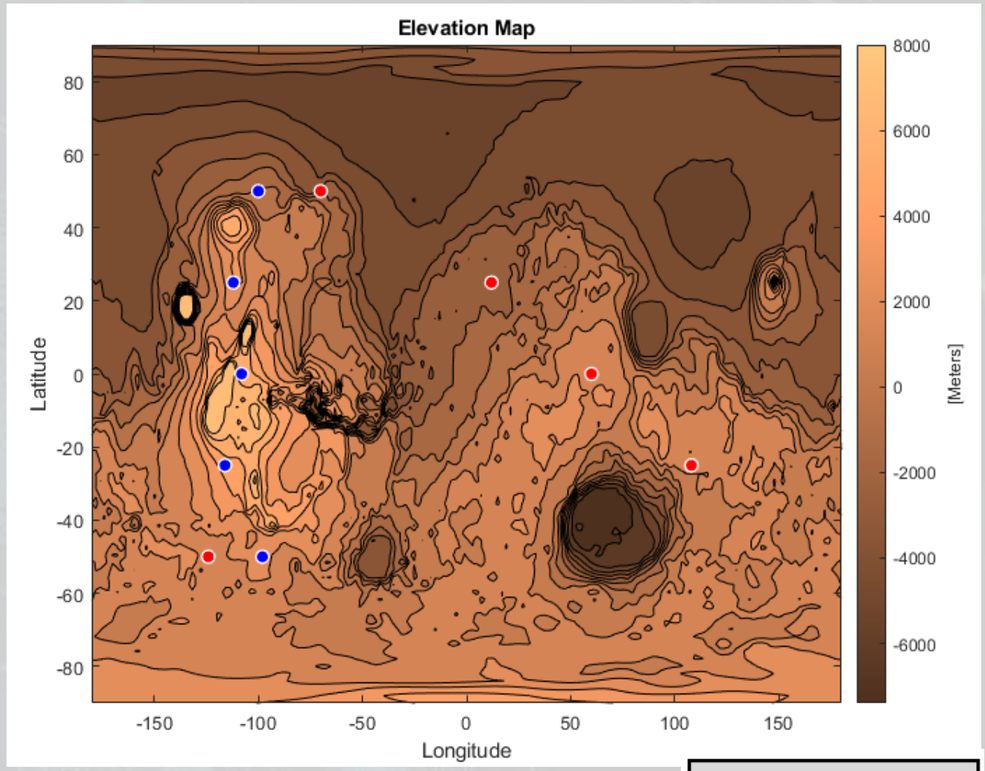
Mar Lowest Average Global Pressure



Mars Highest Average Global Pressure

Temperature Environment

- Temperature on Mars was evaluated for Worst Case Hot (WCH) and Worst Case Cold (WCC) for certain parameters
  - Latitudes of -50, -25, 0, +25, and +50
  - Pressure maximum of 7 torr to allow for Spacesuit Water Membrane Evaporator operations
- Temperature limited approximately to the frost point of CO_2 ~ -143°C

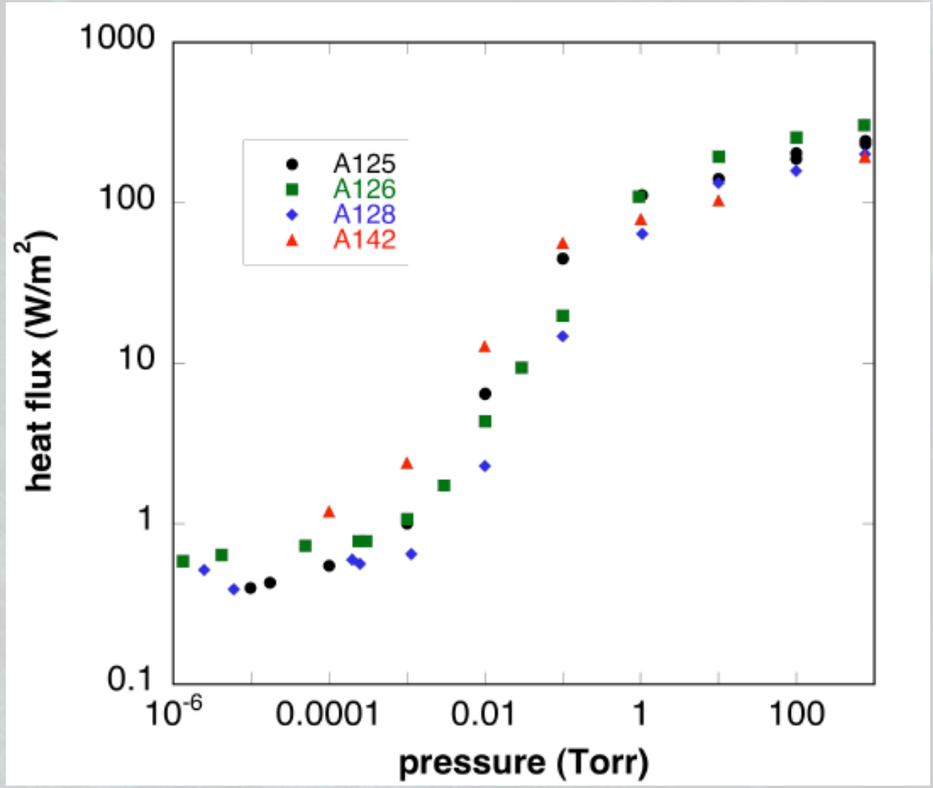


Elevation Map of Mars

Latitude	Condition	Longitude	Surface Temp, K		Atmospheric Temp, K	
			Minimum	Maximum	Minimum	Maximum
-50	WCH	-124	200	303	203	277
	WCC	-98	145	162	146	161
-25	WCH	+108	187	312	193	279
	WCC	-116	148	236	152	222
0	WCH	+60	178	303	183	271
	WCC	-108	144	265	146	237
+25	WCH	+12	148	288	153	260
	WCC	-112	146	265	154	248
+50	WCH	70	191	275	195	256
	WCC	-100	148	177	151	175

Shift In Design Approach

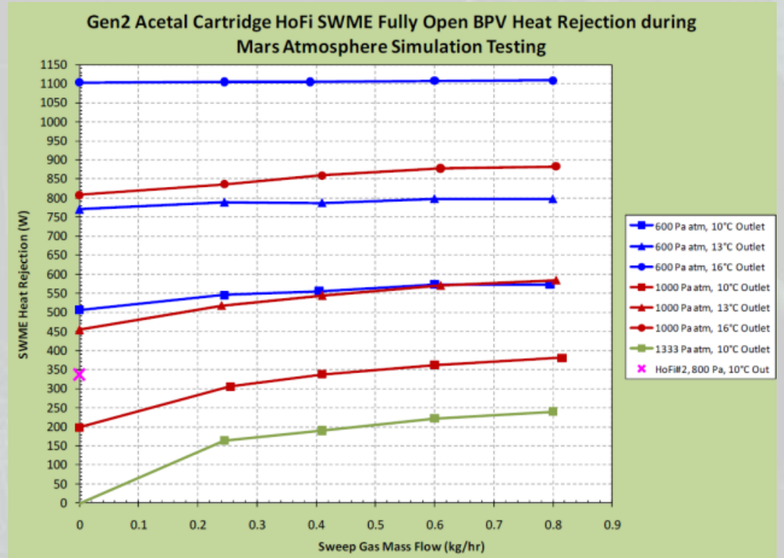
- Suit Mass Prioritization - Options
  - Lunar and microgravity have not had as stringent requirement on mass
  - Return fault tolerance to single like EMU and Apollo (xEMU has 2 fault tolerance)
  - Integrated, custom suit over modular (like Apollo)
  - Reduce heavier regenerable systems (i.e. LiOH instead of RCA + sweep gas)
  - Return to BLSS and remove auxiliary cooling system (like Apollo)
  - Reduce EVA time (i.e. 4 hours instead of 8)
- Insulation
  - MLI will not provide adequate insulation on Mars due to the atmosphere negating the insulative properties it provides in hard vacuum
    - Heat flux transitions around 0.01-1 torr
  - Much thicker traditional synthetics or aerogels will need to be tested and used for Mars
    - This is expected to effect mobility.



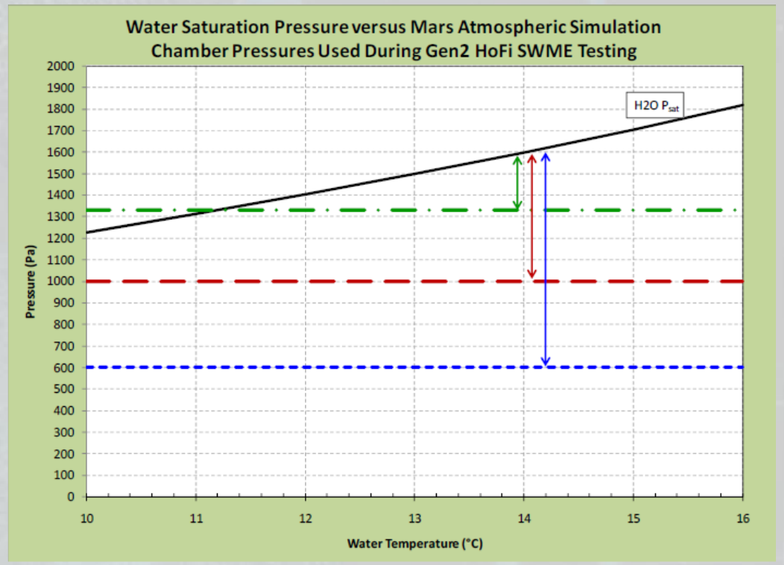
Heat flux versus interstitial gas pressure compared for four different MLI samples

Shift In Design Approach

- CO2 removal
  - LiOH, MetOX, RCA, and newer technologies are being considered
  - RCA will require sweep gas to operate, will not operate as is
  - MetOx is expected to be too heavy for Mars
  - Carbon Dioxide Removal by Ionic Liquid Sorbent for Mobility (CDRILS-M) system and Hollow Fiber Membranes (HFM) using liquid sorbents are new technologies being developed
- Thermal Control
  - SWME is still leading technology for cooling on Mars
  - SWME is expected to have degraded performance at Martian pressures up to 10 torr (1333Pa)
  - Sweep gas may be required for operation at higher Martian pressures
  - SWME normally operates at 50°F (10°C) but may need to operate higher to have a larger saturation pressure difference at higher Martian pressures
- Dust Protection
  - Filters will be required to avoid dust infiltration in the PLSS while maintaining a flow path for SWME



Mars SWME testing with sweep gas



Mars SWME saturation pressure vs. temperature

Deep Space Operation Contingency

- In case of emergency EVA on transit, a space suit may be required
- The PLSS may be cross compatible with microgravity and Mars
- The PGS is less likely to be cross compatible with microgravity and Mars due to the insulation requirements.
  - Deep space requirements may not work well without MLI, which will not work on Mars
  - MLI/insulation is an integral part of the PGS that cannot be readily swapped out
- Both systems will require assessments following optimal design for Mars
- Could consider a hybrid approach
  - i.e. you can use one PLSS with two different PGS for Mars/microgravity

Environment Comparison

	Microgravity/LEO/Deep Space	Lunar	Mars
Gravity	~0	1/6 G	3/8 G
Temperature	138 - 337K (sink temperature)	93 - 377K (sink temperature)	144 - 279K (atmosphere)
Pressure	~0	~0	0.2-9 torr
Dust	No	Yes	Yes - airborne

Mars PLSS Technology Development

- A set of new or modified technologies are being developed for Mars
- Existing technologies will be reused and are not included here
  - Fans, pumps, O2 regulators, tanks, LCVG, pressure sensors, activated carbon for TCC, Thermal Control Ball Valve

1. **Spacesuit Water Membrane Evaporator (SWME)**
   - SWME will need to be evaluated for Mars and is expected some design changes will be implemented for general improvement, sizing, or potential sweep gas implementation. This is being developed at NASA
2. **Condensing Heat Exchanger (CHX)**
   - If LiOH is used for Mars, a method to remove humidity will be necessary (currently removed by RCA). Currently, xEMU PLSS heat exchanger does not remove humidity. Multiple vendors are working on a condensing heat exchanger option.
3. **Lithium Hydroxide (LiOH)**
   - As a lightweight alternative to RCA, a traditional LiOH approach is being explored. Granular and sheet/block LiOH options are being designed for testing by NASA.
4. **Rapid Cycle Amine (RCA) Swing bed**
   - RCA, while it will not work as is due to the CO2 atmosphere, is being investigated using sweep gas to allow operation on Mars. Multiple vendors have been tasked to explore this option
5. **Carbon Dioxide Removal by Ionic Liquid Sorbent for Mobility (CDRILS-M)**
   - As an alternative to current CO2 removal methods, Honeywell is exploring and testing an ionic liquid sorbent to trap carbon dioxide. This system may also remove humidity, eliminating the need to a CHX.

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Mars PLSS Technology Development (Cont.)

- **Hollow Fiber Modules (HFM)**
  - Reaction Systems is developing a CO2 removal systems using a liquid amine sorbent to remove CO2 using hollow fiber membranes
- **Phase Change Material (PCM)**
  - For an auxiliary thermal control loop, a phase change material such as ice is being considered for short term emergency cooling.
- **Batteries**
  - Next generation batteries are being evaluated and tested at NASA looking at a monolithic battery design and solid-state battery options
- **Avionics**
  - Lighter weight, power, size, and radiation tolerant avionics will be required for the PLSS. New chipsets have become available since xEMU that are being evaluated/tested. Additionally, the Caution and Warning systems will need to be evaluated from a limited mission control support due to comms delay with Mars.
- **Forced Convection Heat Exchanger**
  - As an alternative to using a SWME, the cold atmosphere on Mars could be used to help cool the suit without having to consume water for cooling. A vendor is evaluating this potential concept.
- **Filters**
  - To protect from dust intrusion into the PLSS while still allowing the SWME to exhaust, filters will need to be added to protect the fine 0-10um size dust

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Mars PLSS Technology Development

- **Feedwater Supply Volume Sensing**
  - A volume sensor for a flexible water bladder in microgravity has been tested and developed by a vendor. This would replace the secondary water bladder that cracks open once the primary is used to detect a low water condition.
- **CO2 and Gas Sensing**
  - Multiple Vendors are developing new, lighter weight approaches for detecting CO2 in the suit. They are also evaluating options to measure oxygen in addition to CO2.
- **Advanced Trace Contaminant Control (TCC)**
  - New regenerable TCC media is being developed by multiple vendors that can regenerate using the vacuum of space. This would replace traditional activated carbon and integrate with RCA beds for simultaneous regeneration when exposed to vacuum.
- **Check Valve**
  - Previous xEMU check valves have struggles to meet both back leakage and low delta pressure requirements. New designs will need to be developed to improve this technology.
- **Flowmeter**
  - Previous suits have relied on a flow switch for EMU and a flowmeter across the heat exchanger with xEMU. For a CHX, a new flowmeter will need to be developed to measure flow.
- **Lightweight Materials**
  - Lightweight advanced materials such as machined PEEK, Ultem, carbon/glass filled versions, and high-performance additive manufactured materials (nylon + carbon fiber) are being tested at NASA to determine feasibility of including them on the suit in critical location in extreme environments.

Conclusion

- Mars Environment will present a unique challenge to meet requirements
  - Atmosphere presence, higher gravity, and extreme temperatures will drive design
- Early suit designs should consider a low number of EVAs (up to 25) for a short stay initial mission on Mars
- The suit mass requirements will heavily drive suit design leading to a shift in approach
  - Lighter weight components, single fault tolerance, less regenerability, integrated design, and lowered EVA time are in the trade space
- Many existing components will not work on Mars and a pivot or redesign may be necessary
  - MLI will not work on Mars
  - RCA will only work with a sweep gas
  - SWME may need a sweep gas
  - Many other technologies are being considered as alternative approaches
- Mars suits may need to operate in deep space as an operational contingency, so compatibility with microgravity may be necessary, or a separate suit design may be needed

Thank you!

Questions?

Please see associated paper for references

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