xEMU Thermal Vacuum Testing Overview

D. Westheimer and Liana Rodriggs

NASA JSC, Houston, Texas, 77058

Eric Falconi, Ben Swartout, and Michael Lewandowski

Jacobs Technology, Houston, Texas, 77058

Introduction

- NASA has been in a continual phase of spacesuit development since the mid-2000's which culminated in the Exploration Extravehicular Mobility Unit (xEMU)
- Over the past two years, NASA has been performing integrated Design Verification Tests (DVT) with the xEMU, culminating in a thermal-vacuum test in the fall of 2023 in NASA-JSC's Chamber B
- Two suits: the Short-xEMU (SxEMU) and "Suit 2" were tested for about a week to evaluate the performance of the xEMU in a space-like environment
- This presentation provides an overview of the test series, while many additional papers will concentrate on detailed performance of different aspects of the xEMU design
- These findings and lessons learned serve as a government reference for current xEVAS suit developers, a performance baseline for the xEMU, provide an identification of technology needs for future spacesuit development efforts, and serve as a pathfinder for a new wave of similar spacesuit vacuum tests needed to replace the EMU on the International Space Station (ISS) or put humans back on the Moon

References

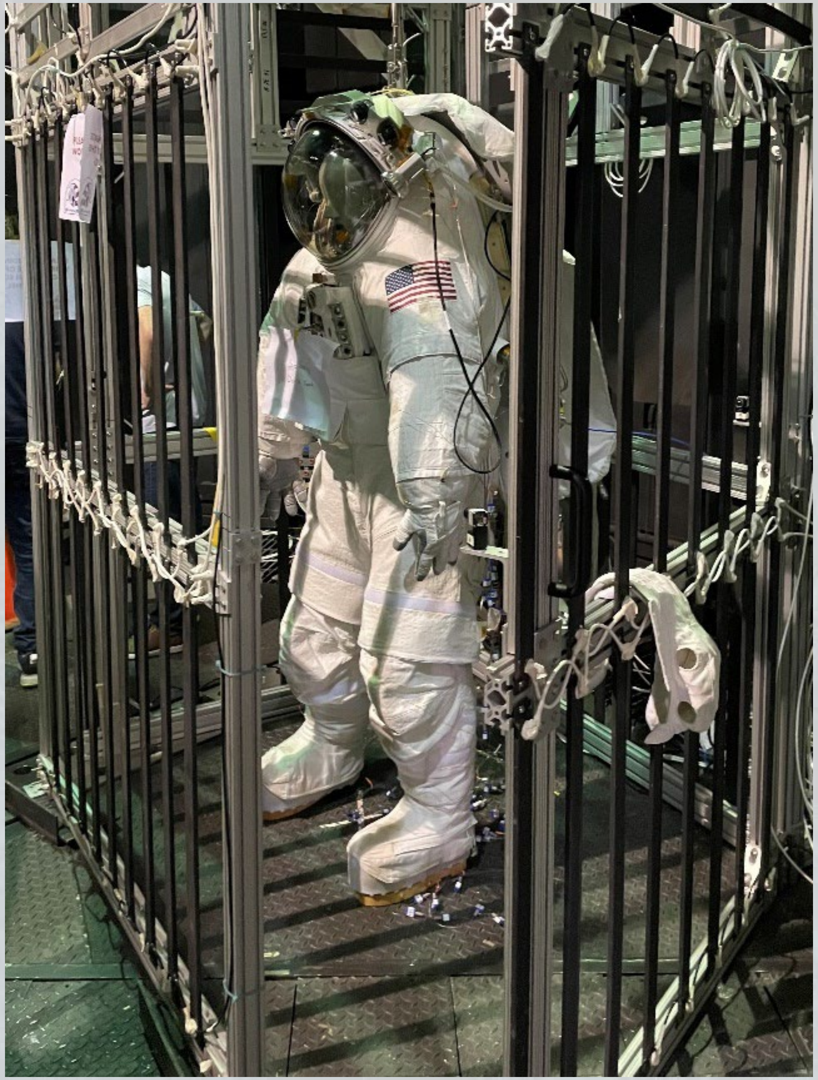
Session	Paper Number	Title
400	64	xEMU Suit Integrated Audio Communications System: Ambient and EVA Pressure Testing System Performance
408	76	Short xEMU Pressure Garment Thermal Vacuum Test Results
408	81	Comparison of Exploration Portable Life Support Subsystem (xPLSS) Thermal Modeling to Thermal Vacuum Testing
408	122	Analytical Review of Exploration Extravehicular Mobility Unit Heat Rejection Performance
408	130	Short Exploration Extravehicular Mobility Unit Testing Setup: Evaluation Under Realistic Pressure and Thermal Conditions
408	213	Exploration Extravehicular Mobility Unit (xEMU) Chamber B Thermal Vacuum “Suit 2” Pressure Garment System Test Article Results
408	215	Exploration Extravehicular Mobility Unit (xEMU) Hard Upper Torso (HUT) Chamber B Thermal Vacuum Testing Results
408	216	Exploration Extravehicular Mobility Unit (xEMU) Chamber B Thermal Vacuum Helmet and Extravehicular Visor Assembly (EVVA) Testing Results
408	217	Exploration Extravehicular Mobility Unit (xEMU) Lunar Boot Chamber B Thermal Vacuum Testing Results
408	219	Exploration Extravehicular Mobility Unit (xEMU) Chamber B thermal Vacuum “Suit 2” Pressure Garment System Hardware and Test Design

Test Objectives

- Test the xEMU in a high-fidelity space-like environment
  - xEMU Thermal requirements were driven by a crater on the south pole of the Moon
    - 93K to 378K (-292°F to +220°F)
    - Thermal environments were controlled by a combination of liquid nitrogen cooled chamber shrouds and heater cages
    - The test configuration could not get the full cold portion of the required range
  - Sub ambient pressure operations impact pressure transients within the suit (especially since the xEMU thermal loops are in the Exploration Pressure Garment System (xPGS)), audio system performance, life support system performance, avionics, and Pressure Garment System (PGS) component exposure to vacuum
  - Integrated testing of complex systems is really, really important

Test Objectives - Images

SxEMU



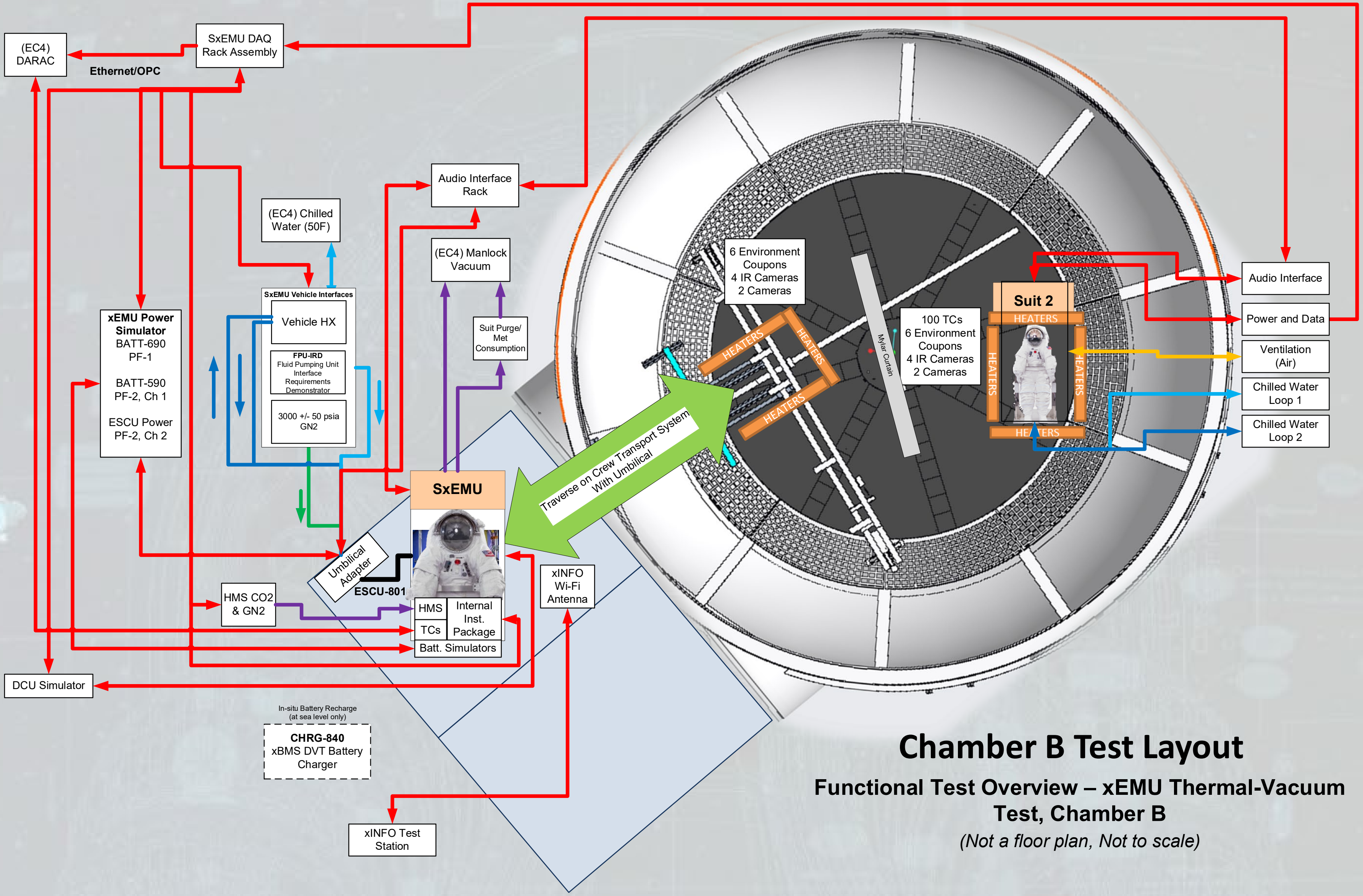
Suit 2

IR Image

Test Configuration

Test Configuration: SxEMU (left), Suit 2 (right)

Test Configuration cont.



Chamber B Test Layout

Functional Test Overview – xEMU Thermal-Vacuum Test, Chamber B

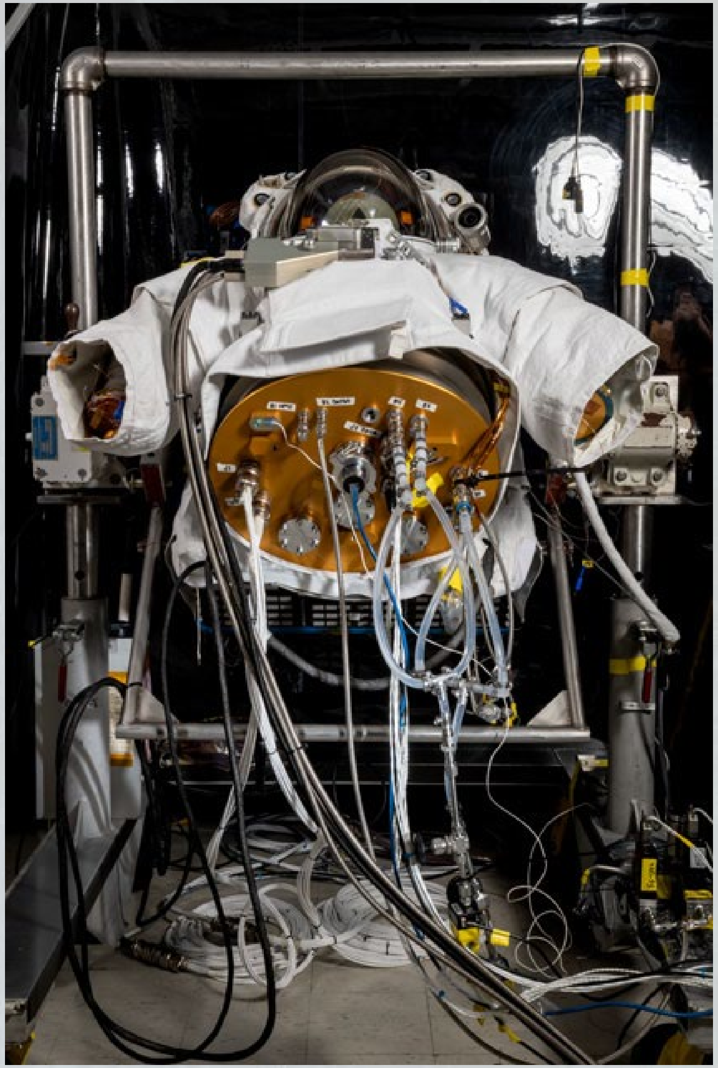
(Not a floor plan, Not to scale)

SxEMU

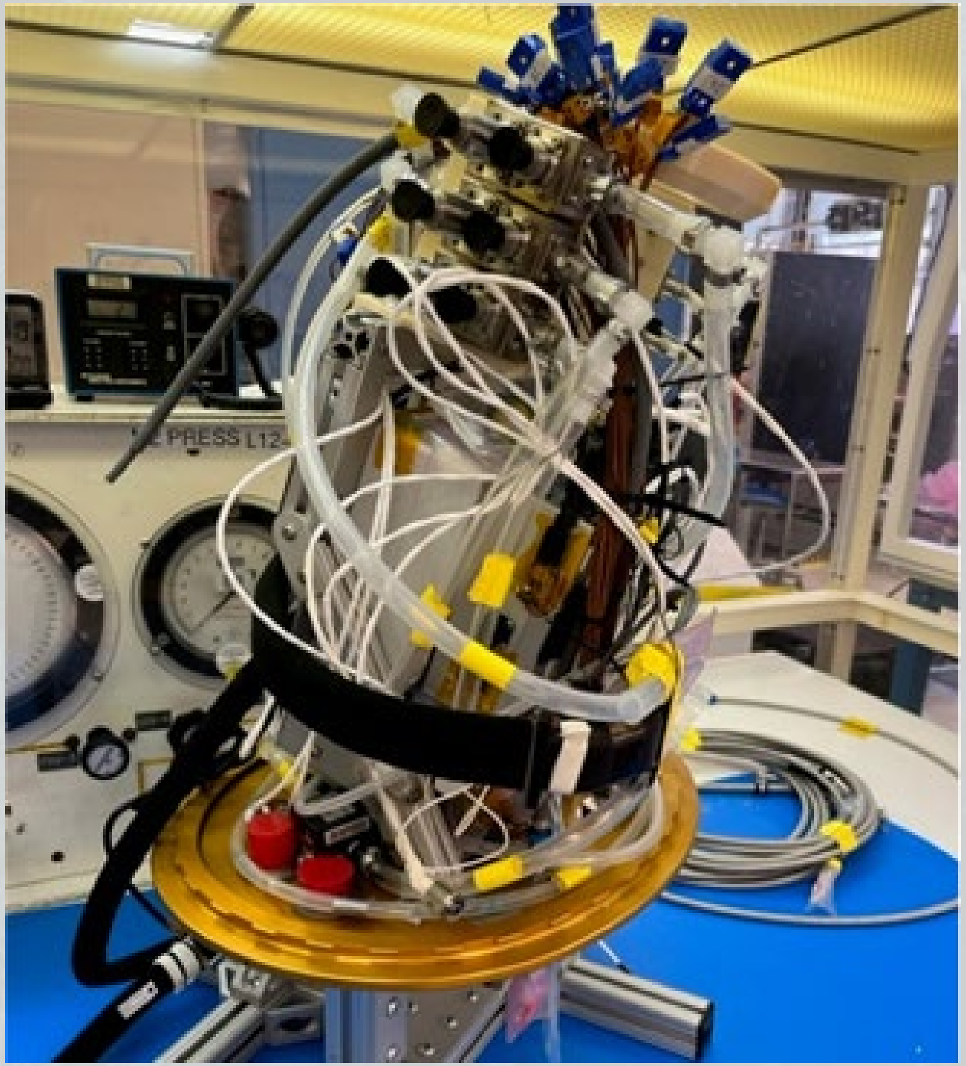
- Full Exploration Portable Life Support System (xPLSS) (nitrogen atmosphere instead of oxygen)
- Partial xPGS: no waist, lower torso, gloves, Liquid Cooling Ventilation Garment (LCVG)
- Full Exploration Informatics (xINFO): lights, camera, informatics (EV-702)
- Crew Transport System via chain driven overhead rails
- Human Metabolic Simulator below the suit
  - Carbon Dioxide (CO_2) and humidity injection
  - Heat input to the thermal loops via coldplates with electrical heaters
- Internal Instrumentation Package inside the upper torso: pressures, temperatures, flow rates, gas composition, audio
- 32 internal thermocouples, 96 external thermocouples

SxEMU - Images

Traversing into the Manlock



Waist Plug



Internal Instrumentation

Suit 2

- Full xPGS configuration including a manikin wearing an LCVG inside of the suit
- xPLSS – All functions simulated with test support equipment
  - Ventilation loop pulled room air through the suit at 4.3 psia and 6 acfm using a small vacuum pump
  - A PLSS thermal loop was run at 50°F (10°C) to simulate PLSS thermal boundaries (backplate, Display and Control Unit (DCU), internal water lines along the Hard Upper Torso (HUT))
  - An LCVG thermal loop was run between 75 and 85°F (24 – 29°C) to simulate the thermal boundary provided inside of the suit by a human wearing an xEMU cooling garment
- Ultem bodied DCU
- xINFO lights and simulated camera
- Internal data system for water and internal suit surface temperatures
- 48 internal thermocouples, 121 external thermocouples (with some placed above and below the Environmental Protection Garment (EPG))
- Audio test equipment

Suit 2 - Images

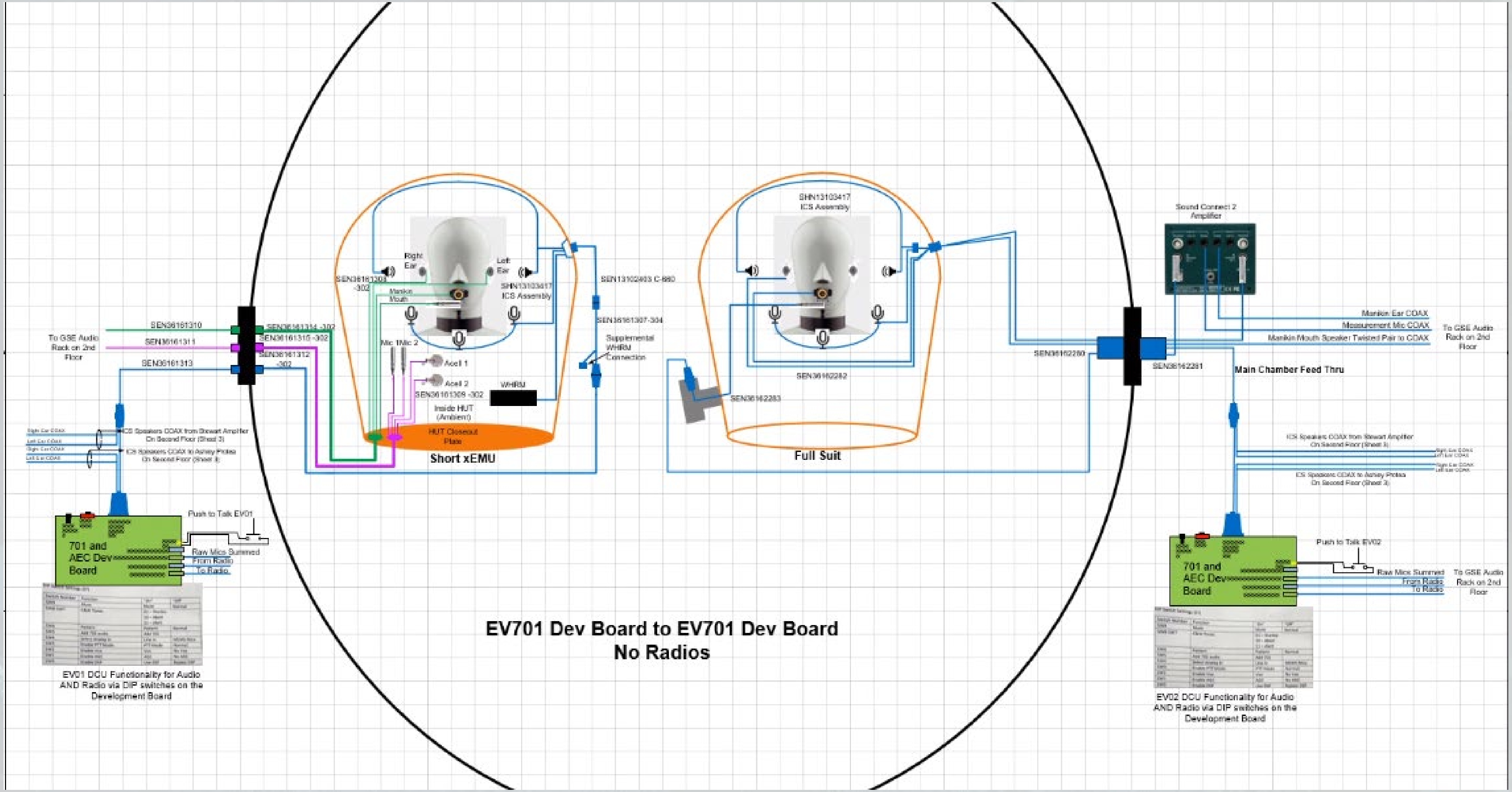
Suit 2

Hand and Foot LCVG Extensions

Audio

- Talking audio manikins in each suit (speaker in the mouth and microphones in the ears)
- Both suits have full Integrated Communication mic array and speakers
- Stand-in radios performing acoustic echo cancelation functions interfacing to a set of test racks with amplifiers, digital audio workstations, and multichannel recording
- 3 measurement microphones in the SxEMU: On top of the head, at the collar and at an ear
- SxEMU had accelerometers on the neck ring and xPLSS-xPGS interface pad in the hatch
- Single measurement microphone in Suit 2

Audio - Images



EV01 DCU Functionality for Audio AND Radio via DIP switches on the Development Board

EV02 DCU Functionality for Audio AND Radio via DIP switches on the Development Board

Results - SxEMU

- 5 Extravehicular Activities (EVA)s were performed (2 cold, 3 hot)
- Two thermal zones: xPGS and xPLSS
  - xPGS: 40 to 180°F (278 to 355K)
  - xPLSS: -108 to 230°F (195 to 383K)
- Simulated airlock operations to charge water bladders, oxygen (O_2) tanks (with gaseous nitrogen (GN_2)), and batteries
- High fidelity depress and repress operations
- Umbilical had to be disconnected early because the test was uncrewed
- Metabolic profiles ended up being performance mapping tests due to unexpected Rapid Cycle Amine CO_2 removal system performance
- Special test points included checking regulator inhibits, simulated purge operations, elevated suit pressures, and Auxiliary Thermal Control Loop operations

Results – SxEMU cont.

Test Point	1	2	3	4	5
EVA Duration - BATT (hr)	13.7	11.8	11.1	12.6	8.8
Time at Vacuum (hr)	8.8	10.6	9.1	11.4	6.3
GN2 Used (lbm)	0.70	1.76	1.81	1.63	0.74
Water Used (lbm)	4.60	6.45	10.70	9.48	4.73
Metabolic Profile	RCA Mapping, SWME mapping	RCA mapping, SWME mapping	SWME mapping	RCA mapping, SWME mapping	4.3, 5.0, 6.2, and 8.2 psid ops
Environment	Cold	Cold	Hot	Hot	Hot
Visor/Shades	Shade Deployed	Stowed	Deployed	Stowed	Deployed
POR/SOR Inhibit		x			
POV Depletion		x	x	x	
POR Purge		x	x	x	
SOR Purge			x		
ATCL Operations	Airlock			Mapping	

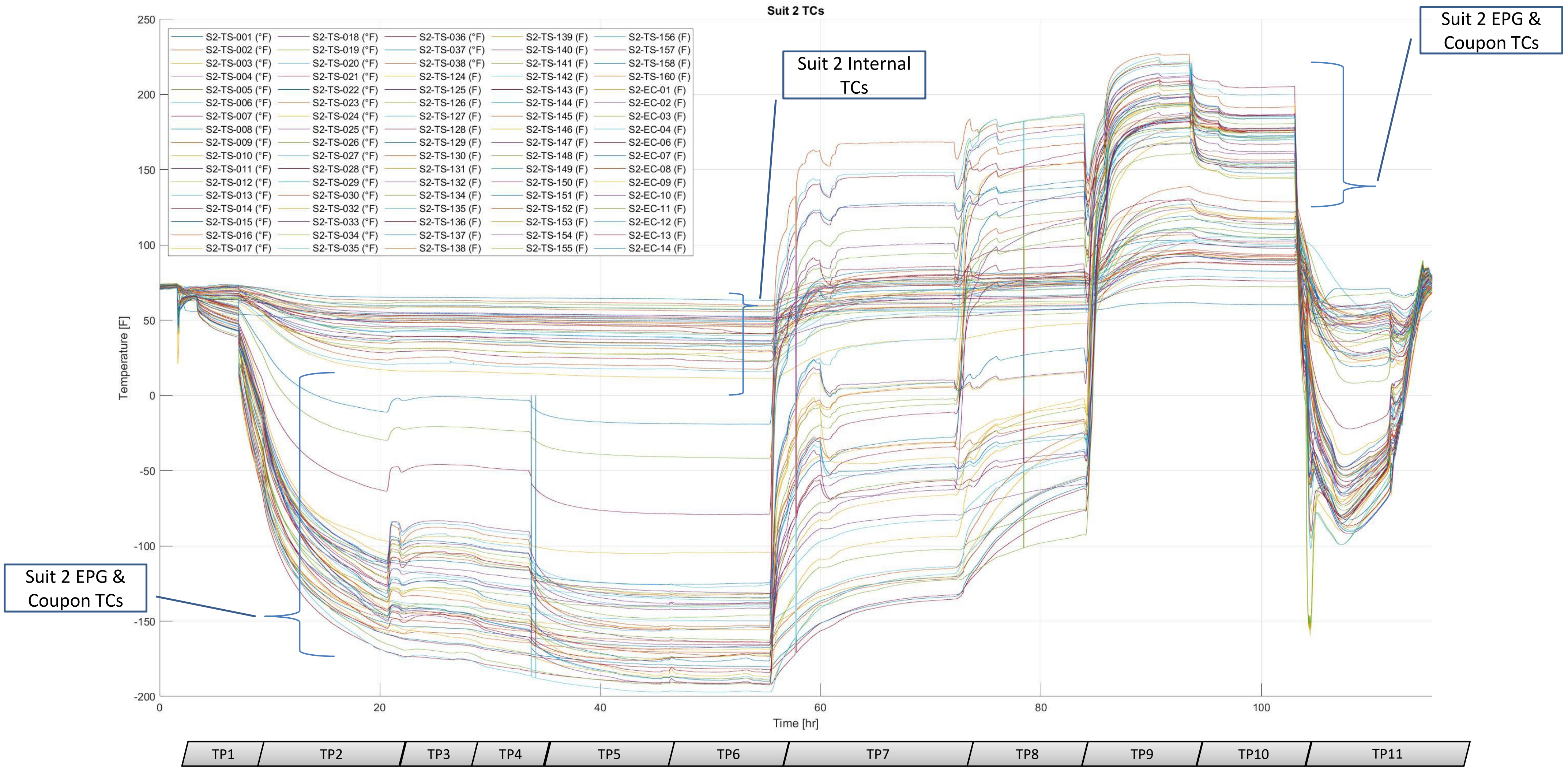
Results – Suit 2

- One continuous 116-hour EVA was performed
- Began with cold thermal environments and incrementally worked up to “mixed” and then hot environments
- Allowed for long duration on test points to reach steady state
- In general, the internal temperatures were controlled to a much more moderate range than the external temperatures
  - EPG worked, large temperature gradients between the environment and inside of the suit
  - More details, including comparisons to internal touch temperature limits, in companion papers
- Internal temperatures ranged from 30°F (272 K) to 100°F (311 K)
- External temperatures ranged from -190°F (150 K) to 230°F (383 K)
- Floor temperatures under the boots ranged from -250°F (116 K) to 165°F (347 K)

Results – Suit 2 cont.

Number	Profile Name	xINFO	Floor LN2	Duration
1	Chamber Cooling	On	On	4 Hr 40 Min
2	Cold	On	On	14 Hr 25 Min
3	Cold (Warming Front of Suit)	On	On	5 Hr 38 Min
4	Cold (Warming Front of Suit)	Off	On	5 Hr 52 Min
5	Max Cold	On	On	11 Hr 46 Min
6	Max Cold	Off	On	8 Hr 20 Min
7	Heating Top Half	On	On	14 Hr 25 Min
8	Heating Front	Off	Off	11 Hr 56 Min
9	Max Hot (Bubble 220F)	On	Off	9 Hr 45 Min
10	Max Hot (Even 200F)	On	Off	9 Hr 36 Min
11	Chamber Warming/Repress	Off	Off	12 Hr 16 Min

Results – Suit 2 cont.



Issues and Anomalies

- xEMU
  - The liquid crystal display (LCD) used in the Display and Control Unit did not perform well at cold temperatures -> this was not unexpected
  - Issues recharging the oxygen tanks (using nitrogen) via the Exploration Service and Cooling Umbilical at large supply to tank pressure gradients
  - xINFO (EV-702) freeze ups and restarts
  - Camera shut off in hot environments -> this was not unexpected
  - Rapid Cycle Amine swing bed degraded performance
  - Auxiliary Thermal Control Loop operations: shut off sequence (need to shut off valve prior to shutting off pump) and potential valve actuator sticking
  - PT-112 (primary oxygen tank) pressure transducer sporadic readings
- Test Equipment
  - Humidity injection from Human Metabolic Simulator into the SxEMU generated a large amount of condensate
  - Infrared cameras overheated during hot test points

Conclusions and Acknowledgments

- Thermal-vacuum testing of the xEMU, via the SxEMU and Suit 2 test articles, was incredibly successful. The xEMU worked in simulated space environments with minimal issues
- This test series was unique in the history of spacesuit development in many ways: uncrewed thermal-vacuum, best suit audio test ever, best boot thermal test to date, highest fidelity operations concepts for the xEMU
- Data from this test will be analyzed for a long time -> check out all of the other papers and presentations for more in-depth results
- The experience our test team gained was invaluable and is being used to help the next wave of spacesuit developers prepare to run similar tests

Acknowledgements & Chamber B Test Team

The authors would like to acknowledge the EVA and Human Surface Mobility Program for funding this test, and also the COUNTLESS team members that have helped to design, develop, assemble, and test the xEMU spacesuit.

Questions?