LEMS

Lunar Environment Monitoring Station

Harness Thermal Heat Loss Measurement for a Lunar Surface-Deployed LEMS Artemis III Payload System TVAC Configuration

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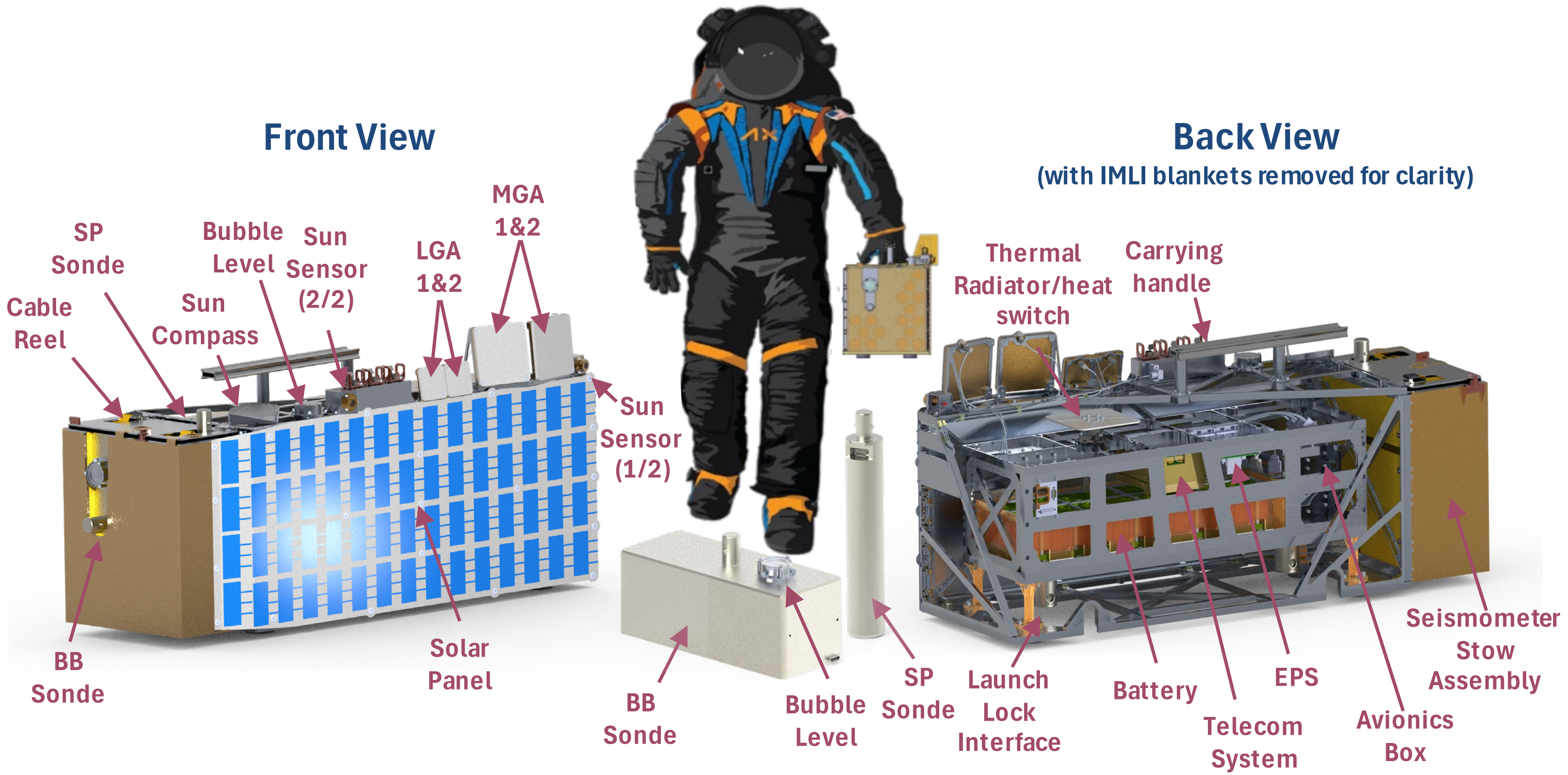
Agenda

- Introduction
- Thermal Conductance Test Configuration
  - Test Objectives
  - Test Set-up
  - Test Profile
- Test Results
- Thermal Model Correlation
- Conclusion

Introduction – What is LEMS?

❖LEMS = Lunar Environment Monitoring Station: A survive-the-lunar-night seismic suite designed to monitor the seismic environment in the lunar surface south polar region continuously for 2 years.



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Thermal Control System Challenges

- LEMS requires a thermal control system that minimizes heat losses to be able to survive and operate continuously through a nominal lunar night, lasting about 360 hours.
- The 1400 W-h battery accommodates an average 2.3 W power consumption between avionics, comms, instruments, and heaters during the lunar night.
- Tight energy budget and cold surface temperatures (-200 C) necessitate accurate measurements of the harness heat leak from the bus to external components.

LEMS Predicted Heat Loss during Lunar Nighttime

Description	Cold Operational Predicted Heat Loss [W]
Bus Launch Lock	-0.483
Integrated Multi-Layer Insulation	-0.252
Signal and Power Passthrough	-0.223
Antenna Coax	-0.238
Radiator Heat Switch	-0.458
Bus Heat Loss	-1.654
Bus Internal Electronics CBE Heat	1.082
Bus Heater (GSE Heater) Power	0.578
Total Internal Electronics Power	1.660
Seismometer-1 As-Measured Power	0.330
Seismometer-2 As-Measured Power	0.330
Total LEMS Power Consumption	2.320

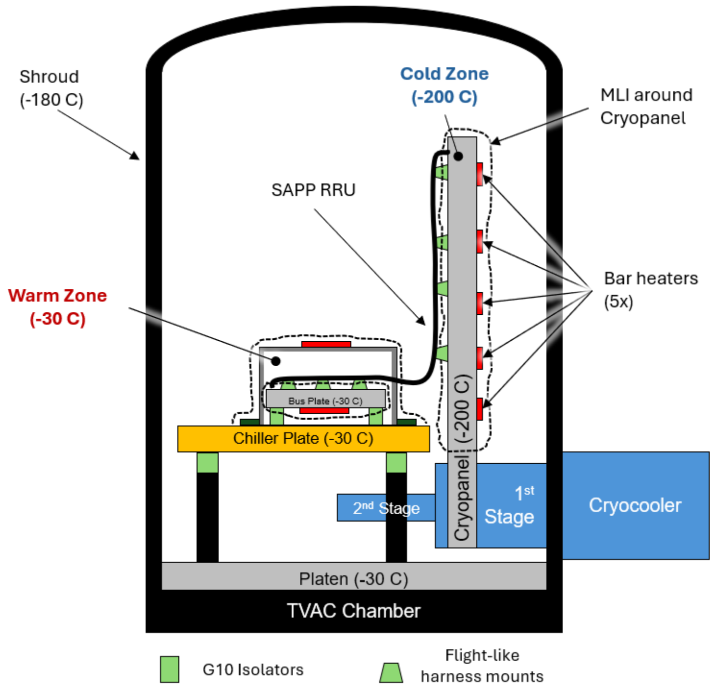
Conductance Test Objectives

- The Signal and Power Passthrough (SAPP) thermal conductance test was conducted to mitigate the risk of excessive heater power demand during lunar night operations, which could result in premature depletion of the LEMS battery.

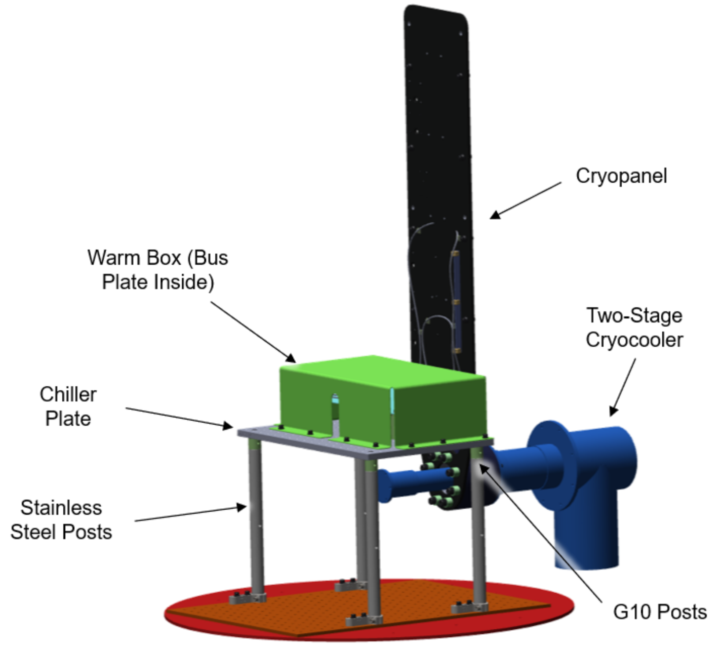
- The SAPP test had two primary objectives:
  1. To measure and characterize the cold operational thermal conductance and total heat leak of a flight-like SAPP Risk Reduction Unit (RRU) under flight-like environmental conditions.
  2. To obtain high-fidelity, independent thermal balance data to support correlation of the SAPP thermal model.

Overview of Test Setup

- Thermal Vacuum Chamber
  - Cylindrical chamber in vertical orientation
  - Dimensions: 12’ diameter x 15’ vertical
  - Presssure pumped down to 1.3×10^{-3} Pa (1×10^{-6} Torr)
- Hardware in test:
  - Flight-like SAPP RRU with flight-like harness mounts and MLI.
  - Ground Support Equipment (GSE)
    - Warm Zone structure to represent LEMS internal heater-controlled environment
      - Bus Plate, Chiller Plate, Warm Box enclosure
    - Cold Zone Cryopanel to represent the external cold structure and components
    - Platen



Test Configuration Block Diagram



Computer-Aided Design Model

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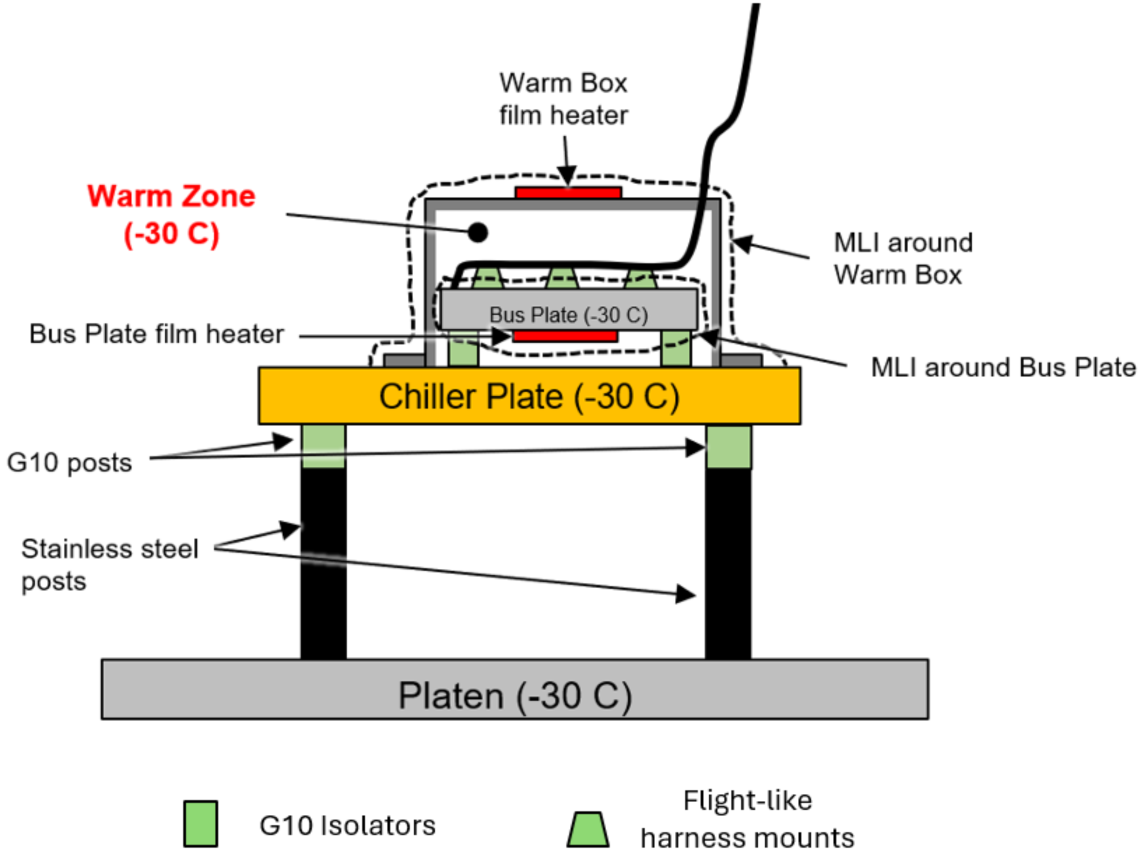
Warm Zone Details

ARTEMIS NASA

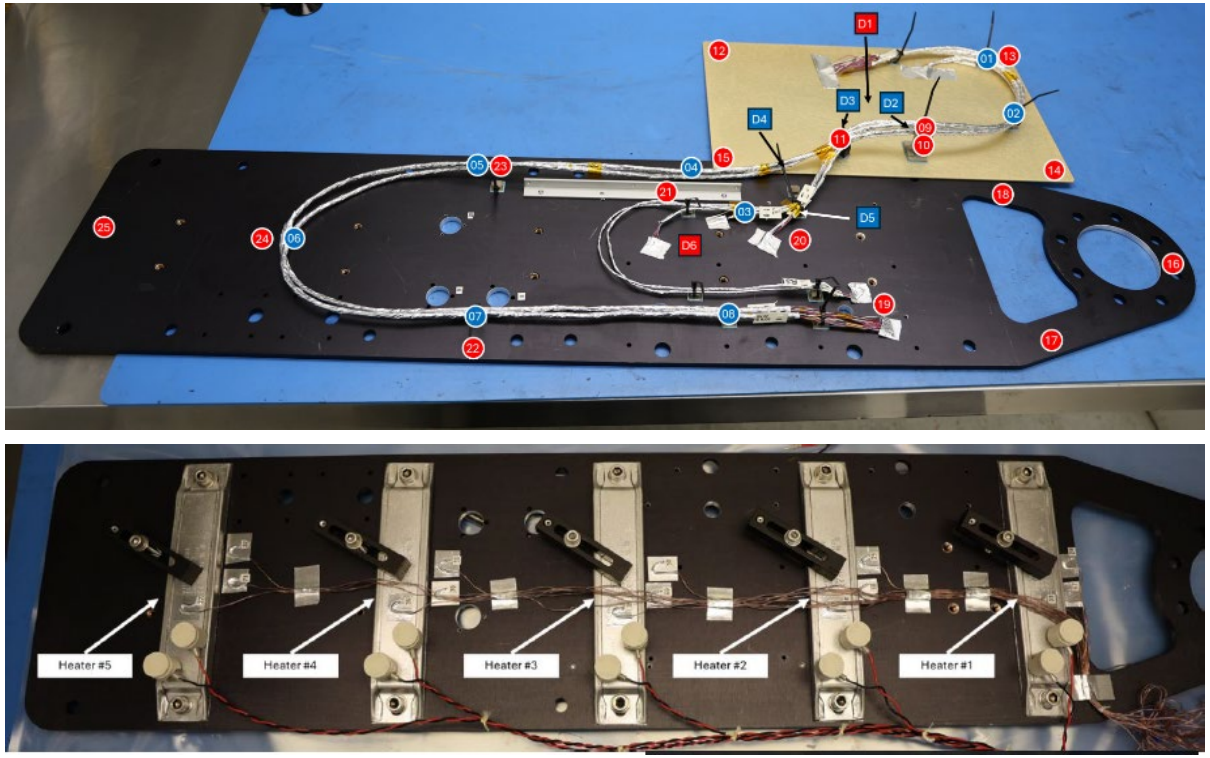
- Bus Plate
  - Aluminum mounting plate used to create the interface temperature sink for the internal SAPP harness segments.
  - Temperature controlled with a 43Ω film heater.
- Chiller Plate
  - Plumbed with circulating fluid to provide temperature control.
  - Chiller Plate is isolated from the Bus Plate to ensure that the SAPP harness is the dominant heat transfer path.
- Warm Box Enclosure
  - Five-sided black anodized aluminum box
  - Temperature controlled with a 43Ω film heater.
  - Exterior of the box enclosure is covered with MLI.



Warm Zone Block Diagram

Cold Zone Details

- Cryopanel
  - Aluminum panel driven by the first stage of a two-stage cryocooler.
  - Five independently controlled bar heaters were distributed across the Cryopanel surface.
  - The SAPP wired ends are stripped and taped to the cryopanel
  - Blanketed with MLI to reduce radiation exchange with the chamber shroud, and to reduce temperature gradients.



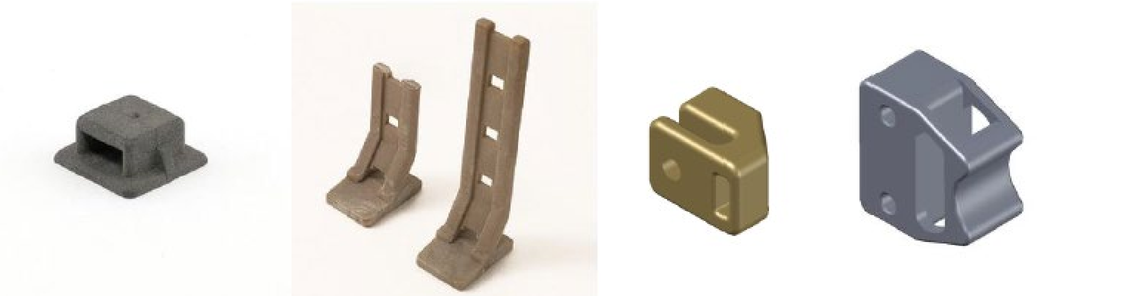
Cryopanel

SAPP Harness Details

- Mix of gauges and materials designed to minimize the thermal conductance while meeting electrical requirements like power, signal quality, and grounding.
  - High-current wires = M22759/33 (CuBe2% Alloy)
  - Low-current wires = manganin
- Sheathed in Teflon® insulation
- Individual wires were bundled and wrapped with Neptape®
- Secured to the structure with Ultem 1000, thermally insulating standoffs.

SAPP Harness Wire List

Gauge (AWG)	Termination	Material	No.
30	Temperature Sensors, Activation Switches, Seismometer Signals	Manganin	50
28	Solar Array Power	Copper Beryllium (2%)	8
30	Seismometer Power	Copper Beryllium (2%)	12
30	Ground	Copper Beryllium (2%)	2

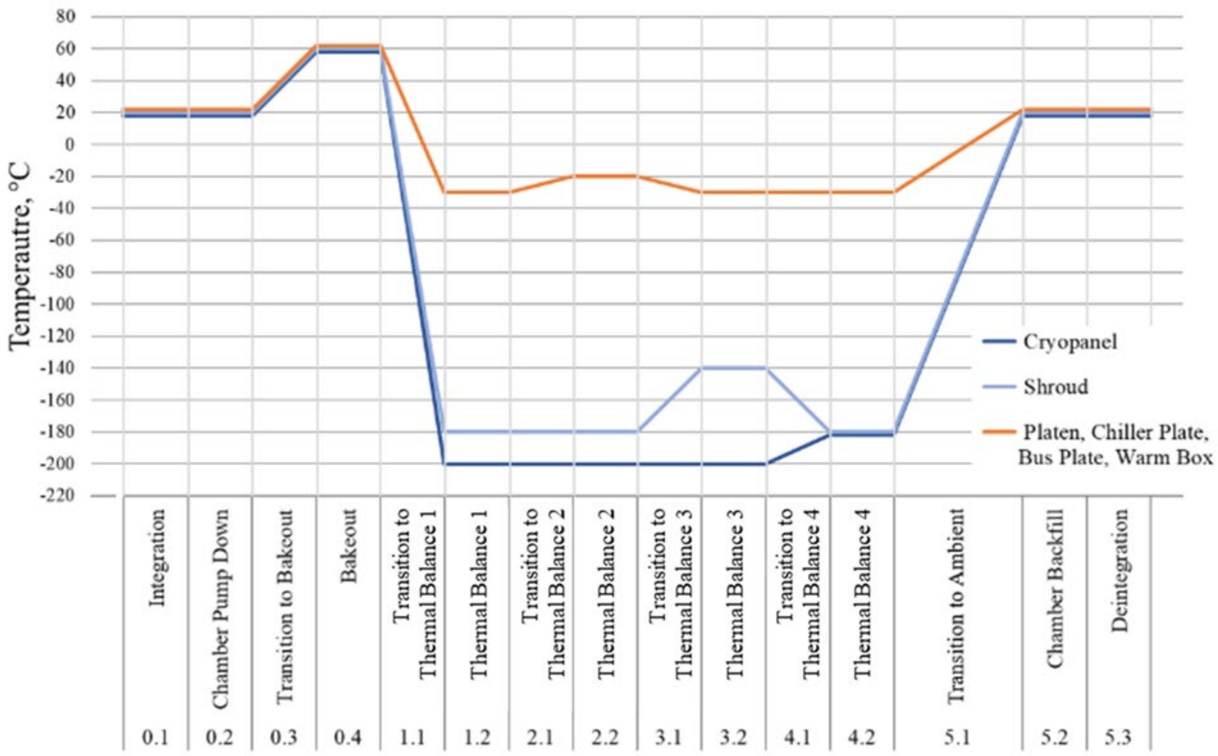


SAPP standoffs for tiedowns. (left to right) ClickBond CB9302, ClickBond CB9257, custom external, custom internal

Test Profile

- The test included 4 balances:
  1. Baseline flight-like thermal environment
  2. Increased warm zone (internal SAPP conductive sink)
  3. Increased chamber shroud temperature (external SAPP radiative sink)
  4. Increased cryopanel temperature (external SAPP conductive sink)
- Balance Stability Criteria:
  - Temperature rate of change < 0.1 ° C/hr
  - Heater power rate of change < 0.01 W/hr

Planned Test profile



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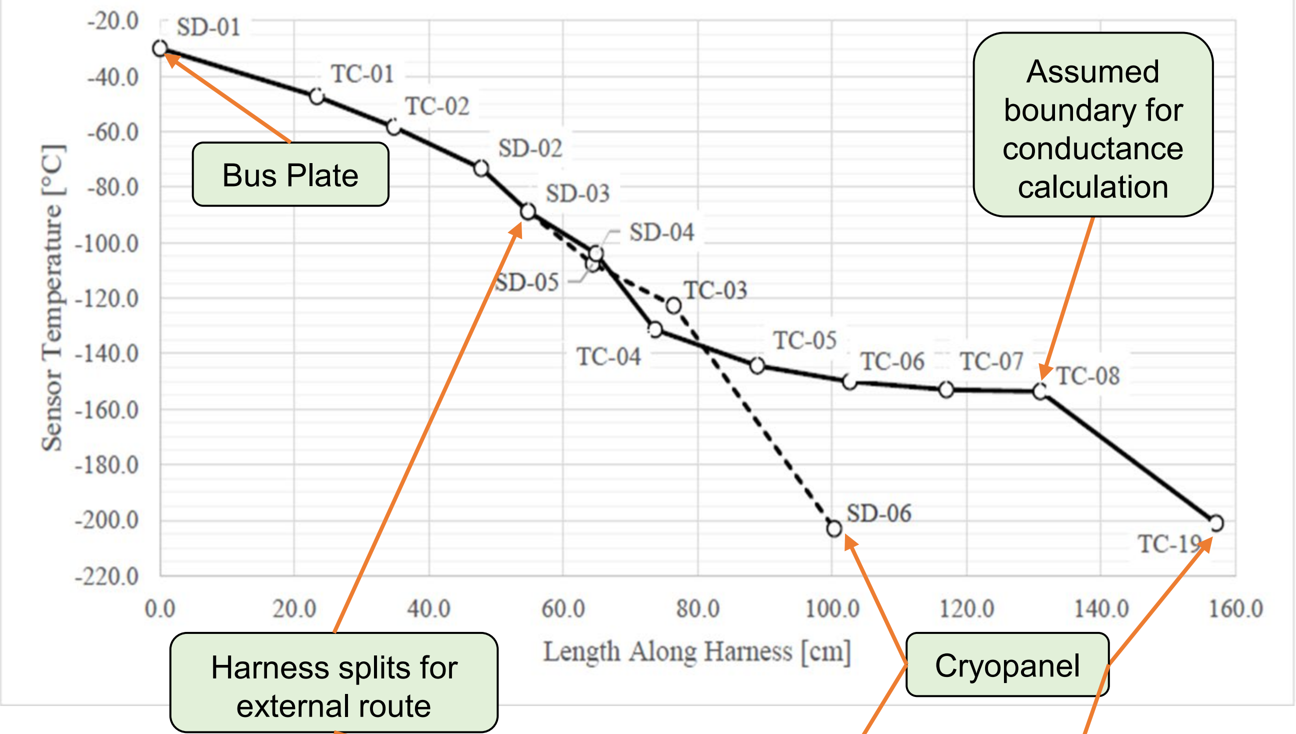
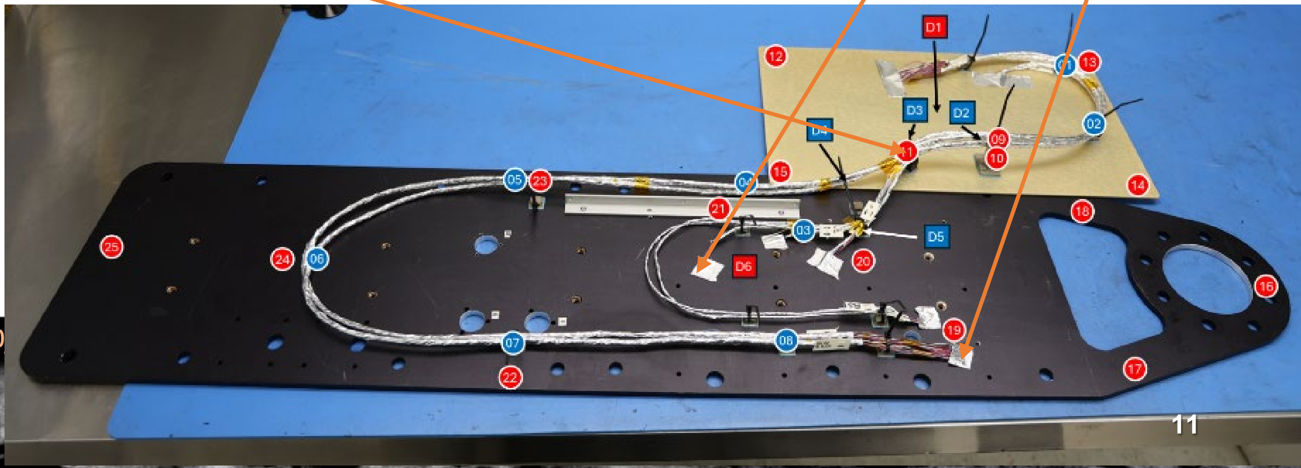
Gradient Along Harness Length

- Bus Plate: SD-01
- Cryopanel: SD-06, TC-19
- Large temperature drop to the cryopanel from TC-03 to SD-06 and TC-08 to TC-19 may be due to tape securing stripped wire to the cryopanel lifting
  - The expected behavior is that the temperature gradient would exhibit a more gradual drop as it gets to the cryopanel boundary

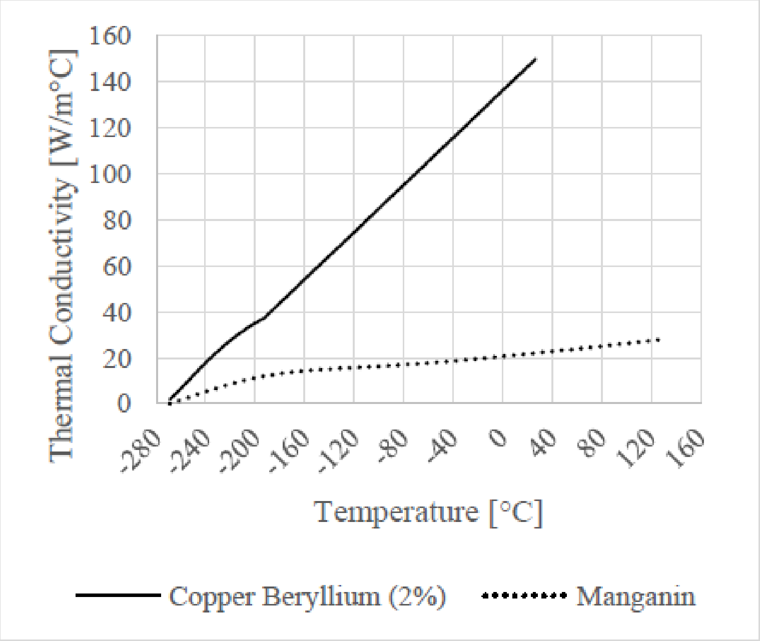




Harness Conduction

- Due to the potential tape lifting at the cryopanel, TC-08 was taken as the boundary condition with:
  - Bus plate = -30 C
  - Cryopanel = -157 C
  - Heat Loss = 0.117 W
  - Conductance = **9.5E-05 W/C**
- Extrapolating the heat flow calculation to a boundary of -200 C gives a heat loss of **0.162 W**
  - A simple linear extrapolation is only appropriate if the harness materials' thermal conductivity decreases between -157 C and -200 C

Harness Material Conductivity



Resistance Network Thermal Model

- Resistor-network thermal model was developed to determine the SAPP heat flow error bounds that can result from uncertainty in the temperature measurements.

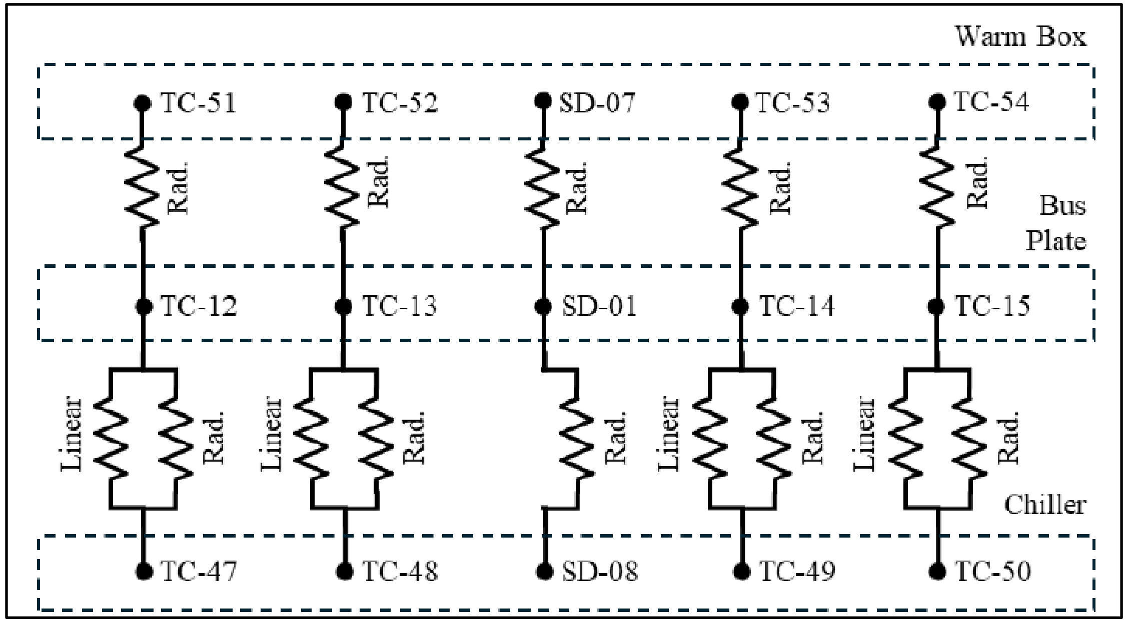
- Conduction Error Calculation - sum of the error associated with the measured temperature delta and the measurement uncertainty of the thermocouples using RSS uncertainty propagation. Example calculation below.

$$conduction\ error = G_{bolt} * (TC_{12} - TC_{47} + \sqrt{\sigma_{TC12}^2 + \sigma_{TC47}^2})$$

- Radiation Error Calculation - heat flow error is calculated as the maximum difference in temperature between the bus plate and the warm box or the chiller plate. Example calculation below.

$$radiation\ error = (0.014)(0.05)(5.67 * 10^{-8})(TC_{12}^4 - TC_{47}^4)$$

Simple Resistor Network



Bus Plate Conductive and Radiative Heat Flow Uncertainty

- The total heat flow error is estimated to be **0.061 W** based on the simplified resistor network model

Label	Sensor for Delta	Temperature Delta (Bus Plate - Boundary) [° C]	Heat Flow Error [W]	
			Linear	Radiative
Bus plate to chiller	SD-01 – SD-08	0.1 ± 0.126	0.000	0.001
	TC-12 – SD-08	1.7 ± 1.421	0.001	0.009
	TC-13 – SD-08	0.4 ± 1.421	0.001	0.006
	TC-14 – SD-08	0.1 ± 1.421	0.001	0.005
	TC-15 – SD-08	1.7 ± 1.421	0.001	0.009
Bus plate to warm box	SD-01 – SD-07	0.0 ± 0.126	-	0.000
	TC-12 – TC-51	0.6 ± 1.421		0.006
	TC-12 – TC-52	0.8 ± 1.421		0.007
	TC-12 – TC-53	0.9 ± 1.421		0.007
	TC-12 – TC-54	1.8 ± 1.421		0.009
Heat Flow Error Subtotal			0.004	0.057
Total Heat Flow Error			0.061	

Conclusion

- The thermal conductance test of the SAPP harnessing was able to measure the heat loss and conductance in a flight-like configuration and environment.
- Systematic and random errors were propagated to build a confidence interval of at least three standard deviations.
  - Further work on the development of a geometric radiation model would improve confidence in the heat flow error estimate.
- The heat leak in a flight-like environment was determined to be **0.162 ± 0.061 W**.
  - This gives a **maximum heat loss of 0.223 W,** which is within predicted values for worst case flight cases.
- Further work on a correlated Thermal Desktop model is needed to meet the second test objective.

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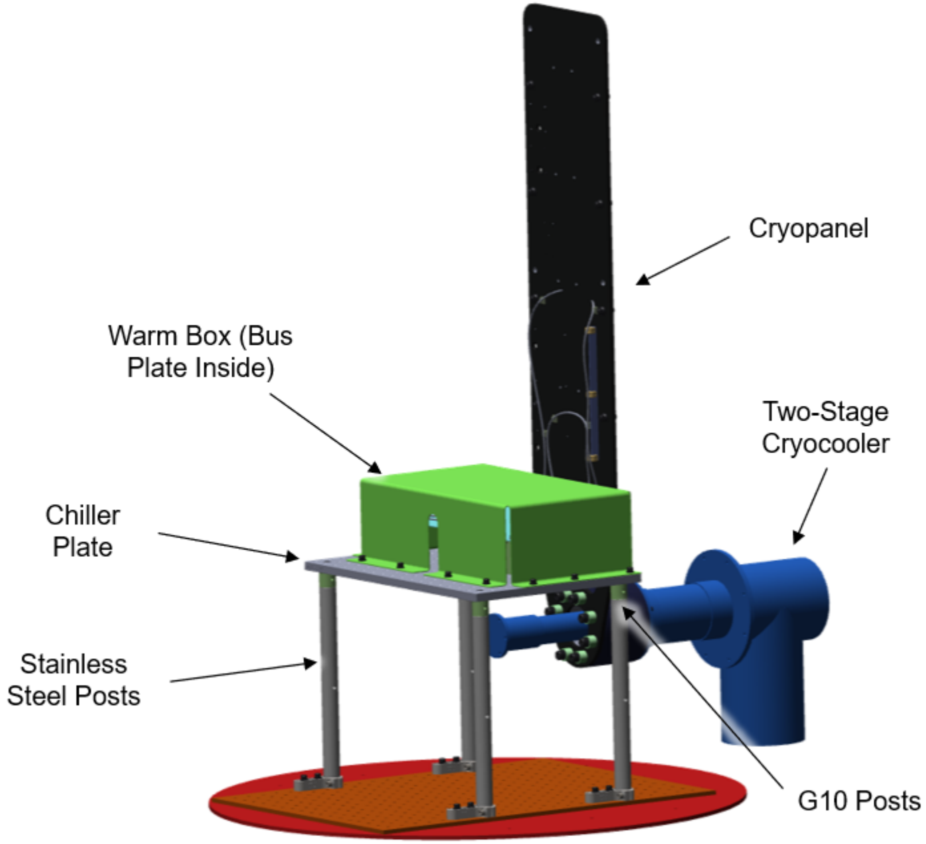
Backup Slides

Acronyms and Nomenclature

- G = Thermal conductance
- GSE = Ground Support Equipment
- I_i = Current Measurement
- LEMS-A3 = Lunar Environment Monitoring Station – Artemis 3
- MLI = Multi-Layer Insulation
- N = Number of measurement samples
- PEEK = Polyether Ether Ketone
- RRU = Risk Reduction Unit
- SAPP = Signal and Power Passthrough
- SD = Silicon Diode
- TC_{XX} = Thermocouple with subscript XX denoting the sensor number
- V_i = Voltage Measurement
- $\bar{x}$ = Average of the sample period
- x_i = Measurement
- σ_{XX} = Measurement uncertainty with XX denoting the relevant sensor

Test Configuration

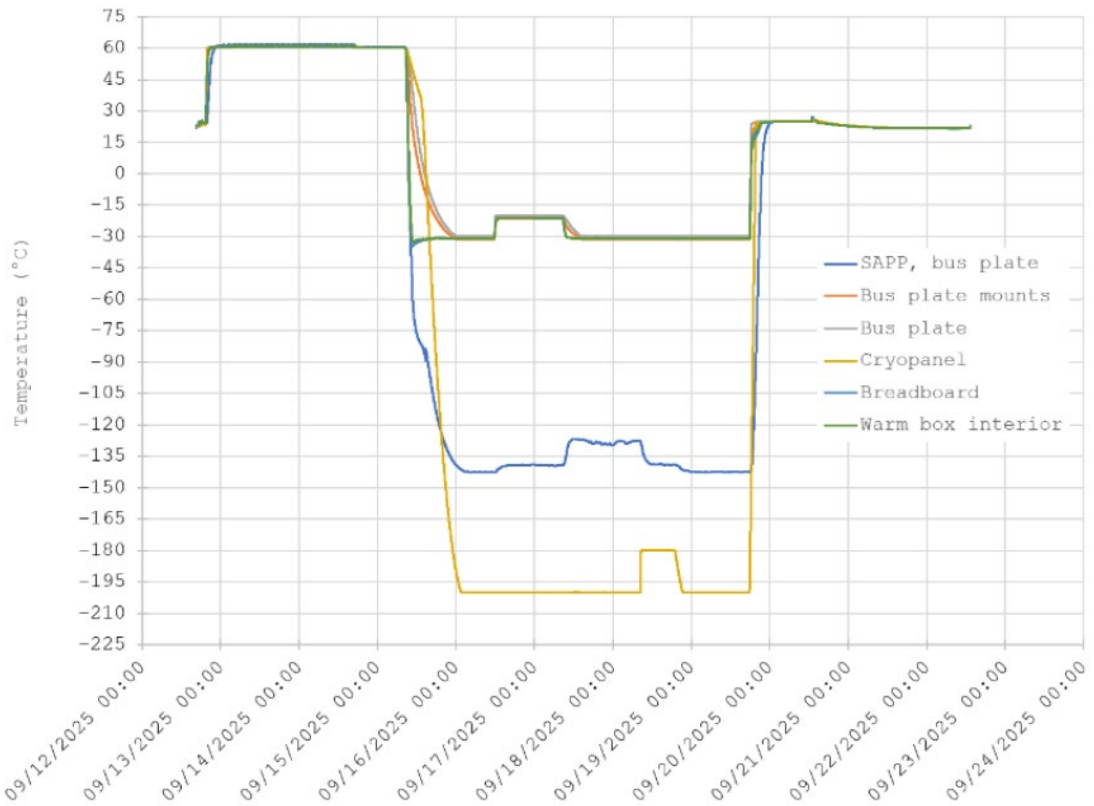
Photos of SAPP Test Configuration



Computer-Aided Design Model

Test Data

As-Run Test Profile



Balance Times

Test Phase	Start	End	Duration [h]	No. Samples (N)
Balance #1	09/16/2025 05:00	09/16/2025 11:00	6	720
Balance #2	09/16/2025 18:00	09/17/2025 06:00	10	1200
Balance #3	09/17/2025 18:00	09/18/2025 08:00	12	1440
Balance #4	09/18/2025 14:00	09/18/2025 18:00	4	480

- Balance Data criteria
  - Temperature rate of change < 0.1 ° C/hr
  - Heater power rate of change < 0.01 W/hr