Thermal Cycle and Capacitance Testing of Mezzo Industries Phase Change Material Heat Capacitor

-Michael C. Johnston, Johnson Space Center

-Jon-Michael Tucker, Johnson Space Center

-Ryan P. Dippolito, Johnson Space Center

-Priscilla Nizio, Johnson Space Center

-Ian Anchondo, Johnson Space Center

-Dongeun Lee, Amentum

EC6 Thermal Systems

Trade names are used in this presentation for identification only. Their usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration

Overview

- Introduction to our Team
- Basic Overview of Spacecraft Active Thermal Control Systems
- Introduction to Phase Change Heat Exchanger Technology
- Previous Work
    - ISS Payload
    - Orion PCM Heat Exchanger
- Mezzo PCM Heat Exchanger Design
- Thermal Capacitance Testing, Methods & Results
- Summary of Current / Forward Work

EC6 (Team) Overview

Lyndon B. Johnson Space Center

Engineering Directorate

Crew & Thermal Systems Division

Thermal Systems Branch

Technology and Special Projects Team

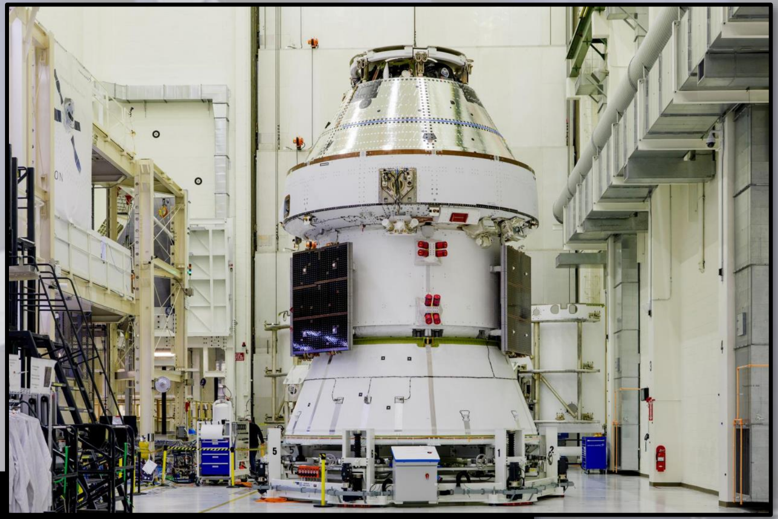
Integrated Space Environment Testing

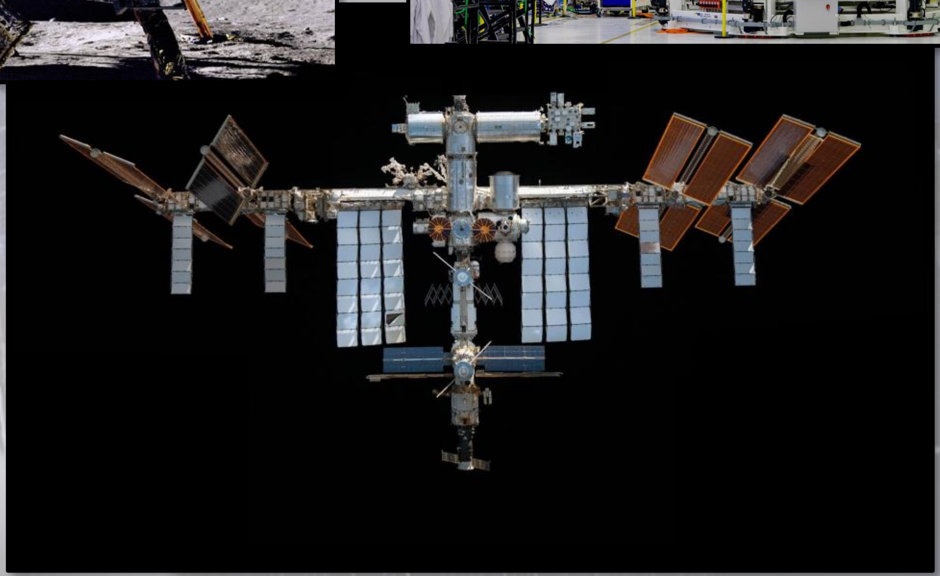
Government Furnished Equipment / Flight Hardware

Technology Development

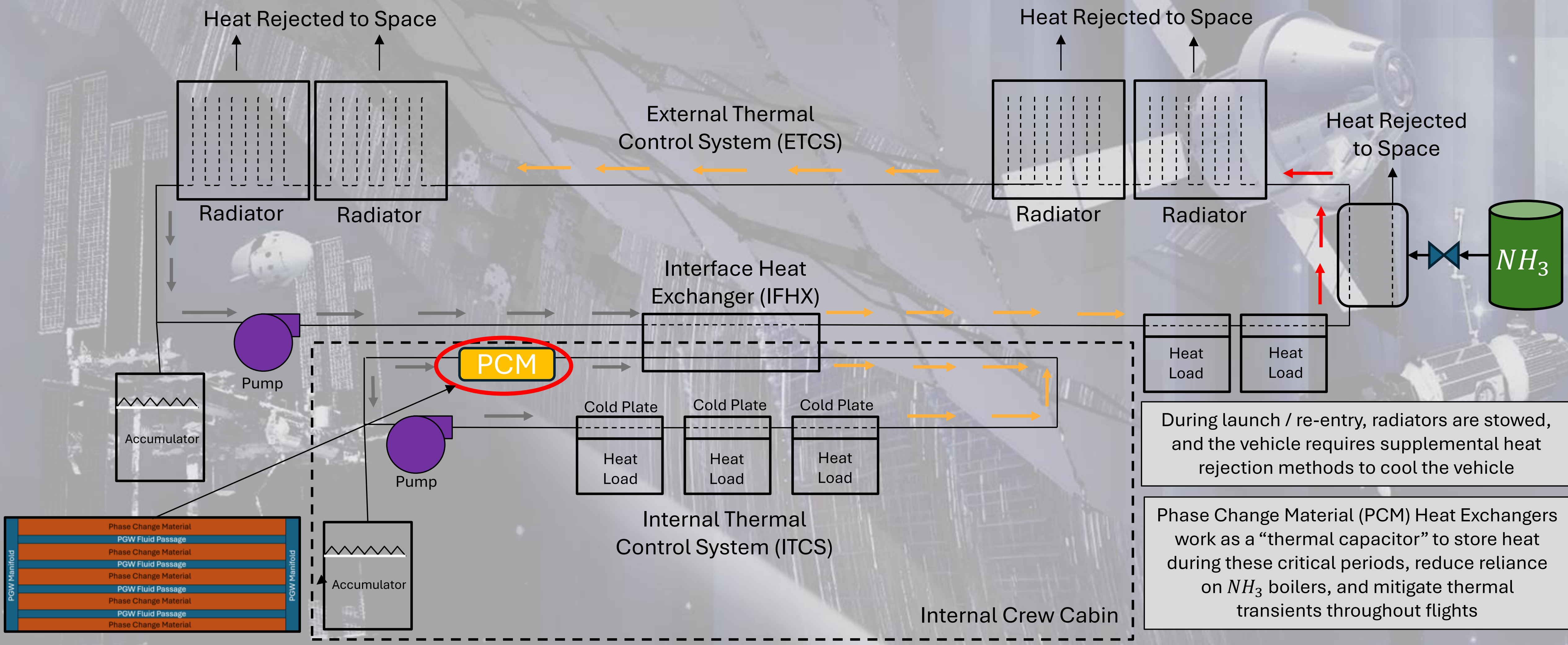
Active Thermal Control Systems (ATCS)

- Human Spaceflight missions (amongst other applications) have high and variable heat loads that necessitate tunable heat rejection capability to keep set points inside the cabin safe and habitable for equipment and crew.
- Active Thermal Control Systems are primarily pumped fluid loops that complete this function and are used on landers, rovers, crew capsules, and space stations / habitats





Basic ATCS Architecture Overview

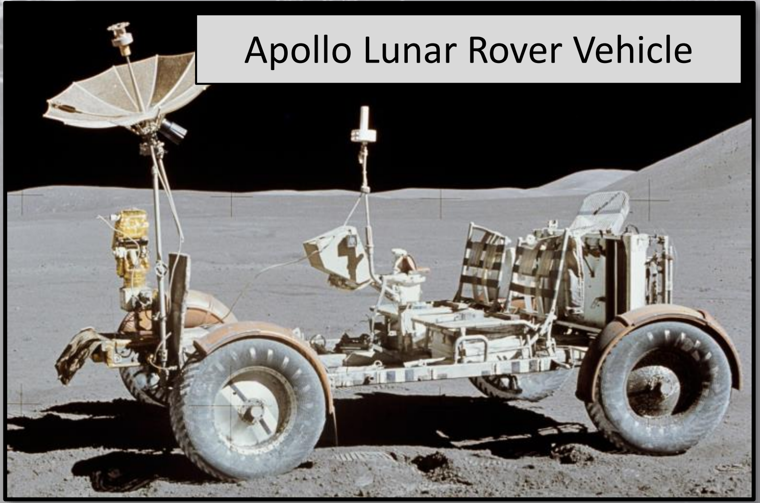


During launch / re-entry, radiators are stowed, and the vehicle requires supplemental heat rejection methods to cool the vehicle

Phase Change Material (PCM) Heat Exchangers work as a “thermal capacitor” to store heat during these critical periods, reduce reliance on NH_3 boilers, and mitigate thermal transients throughout flights

Previous Phase Change Material Work

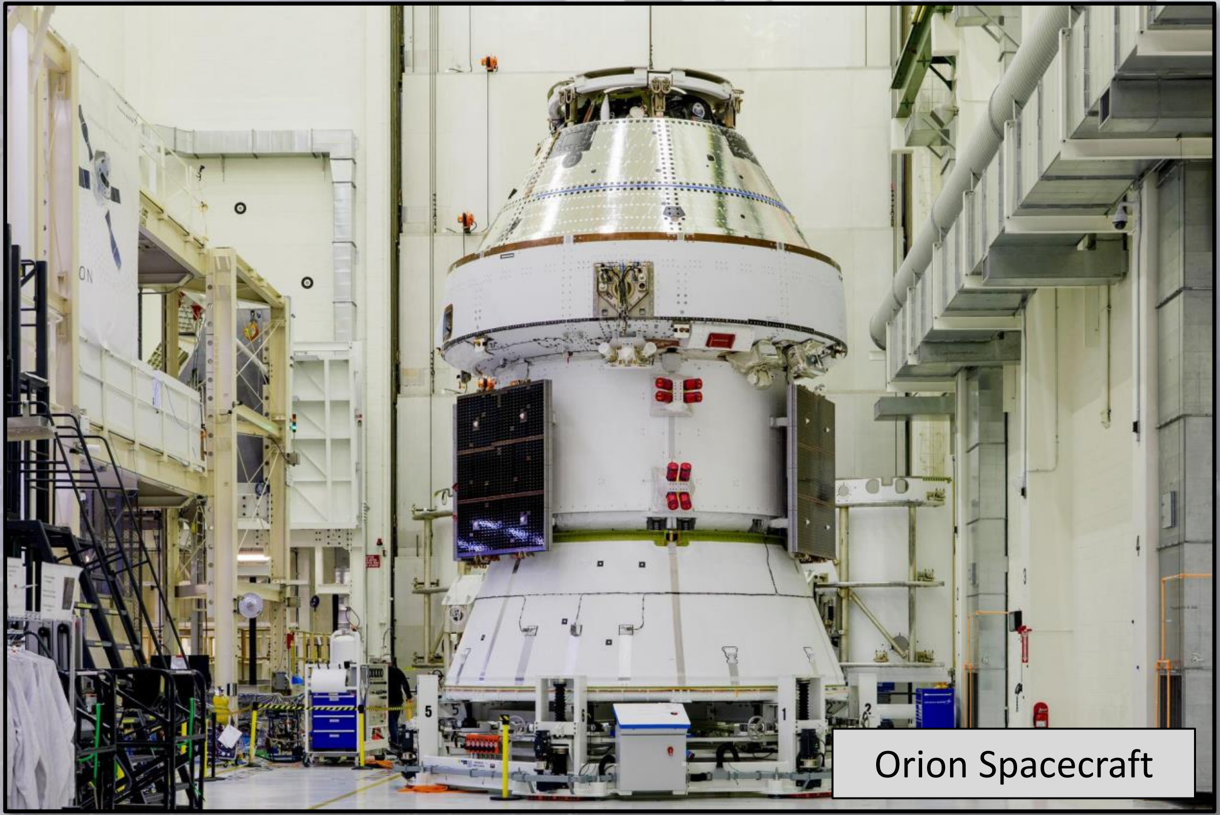
- PCM technology has been used extensively in passive thermal management systems, including wax modules for heat management on the Apollo Lunar Rover Vehicle, and is primarily used on satellites and some microchips.
- EC6 initiated PCM technology development (for Active Thermal Hardware applications) with an ISS flight payload in 2015
  - Issues were found with pressure spikes due to dissolved gases in the phase change material, where phase change due to thermal cycling led to localized pressure spikes that went outside allowable limits.


Apollo Lunar Rover Vehicle

ISS PCM Payload

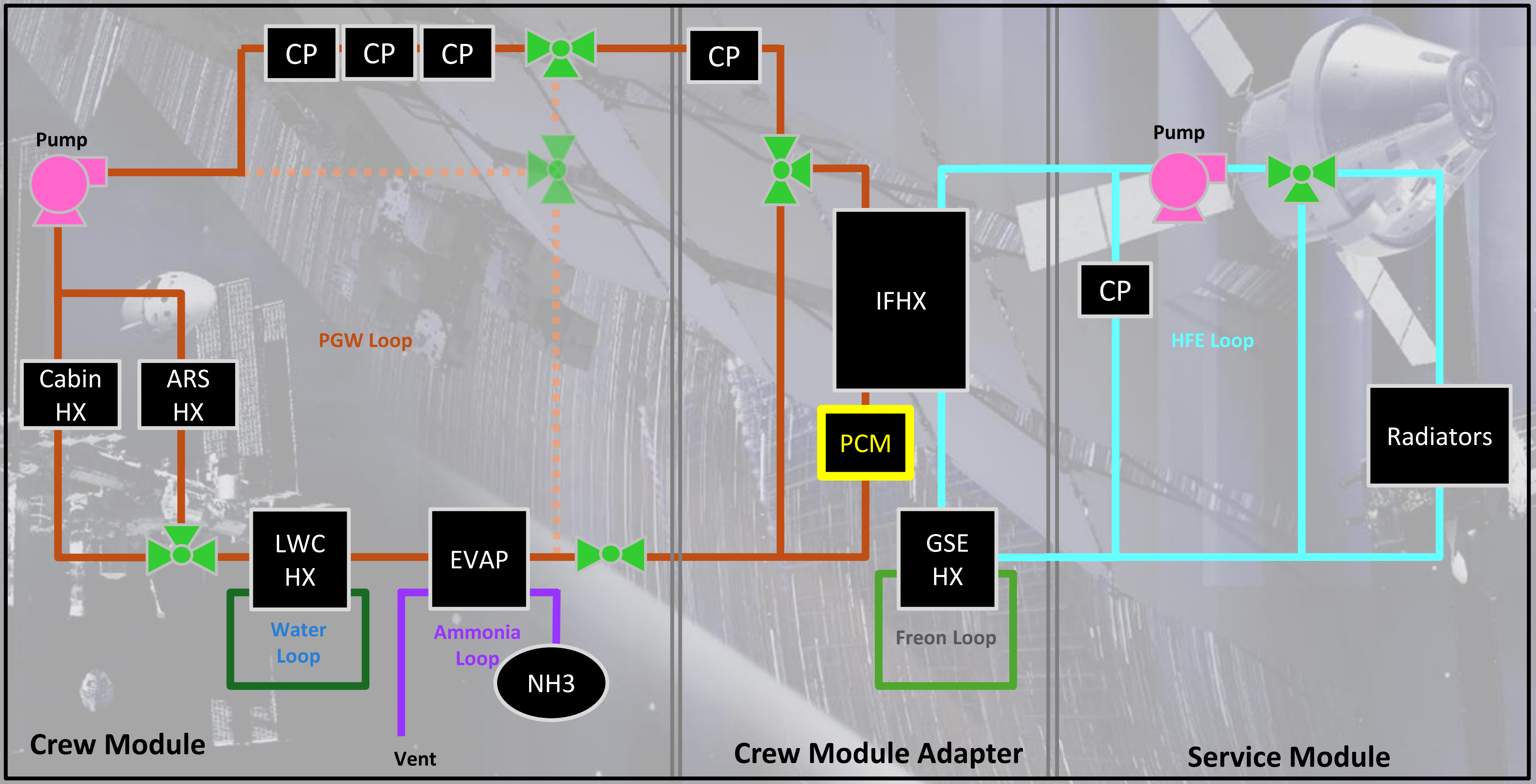
Previous PCM Work / Current State-of-the-Art

- The Orion spacecraft has a PCM heat exchanger that has been used for Artemis 1 and 2 and can be assumed as the current in-use state-of-the-art for spacecraft active thermal systems.
- The current Orion PCM heat exchanger, although meeting performance requirements for heat capacitance:
    - Has experienced structural issues due to brazed layer design that is susceptible to the shock environment from Orion / SLS.
    - Has increased in mass due from strengthening retrofit to mitigate structural issues.
    - Carries heavy cost and lead-time due to complexity of braze manufacturing.
- Due to these issues, EC6 solicited an SBIR topic for alternative PCM heat exchanger designs that meet Orion heat storage requirements, but provide better reliability, simplicity, and mass savings.



Orion Spacecraft

Orion ATCS Architecture

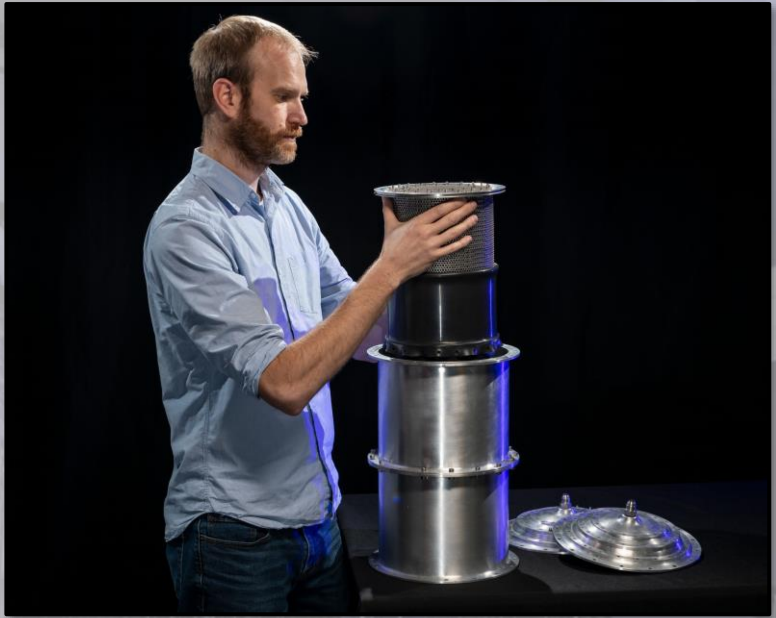


Mezzo PCM Heat Exchanger Design

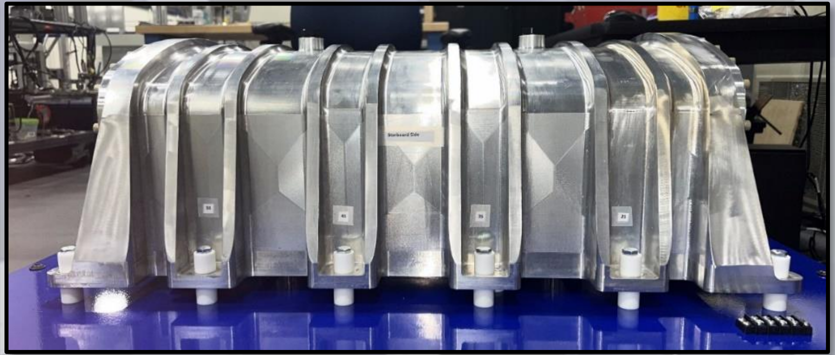
- Mezzo Technologies was awarded a phase 1 SBIR contract to design and manufacture a micro-tube PCM heat exchanger
- Mezzo is known for their robotic laser-welding manufacturing capability, shown to be higher quality, highly repeatable, and lighter weight than traditional layered brazing techniques.
- This heat exchanger was designed to use the same phase change material as Orion, n-pentadecane, to match phase transition temperatures at Orion-emulative conditions

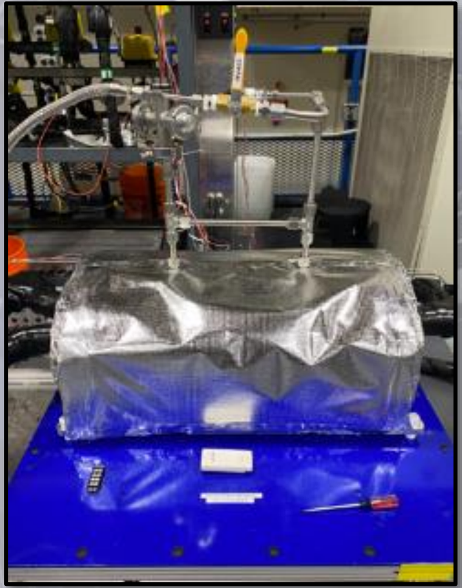
MEZZO TECHNOLOGIES
A Signia Aerospace Company

Current Mezzo prototype demonstrates approximately 17% of weight savings compared to the current Orion heat exchanger.



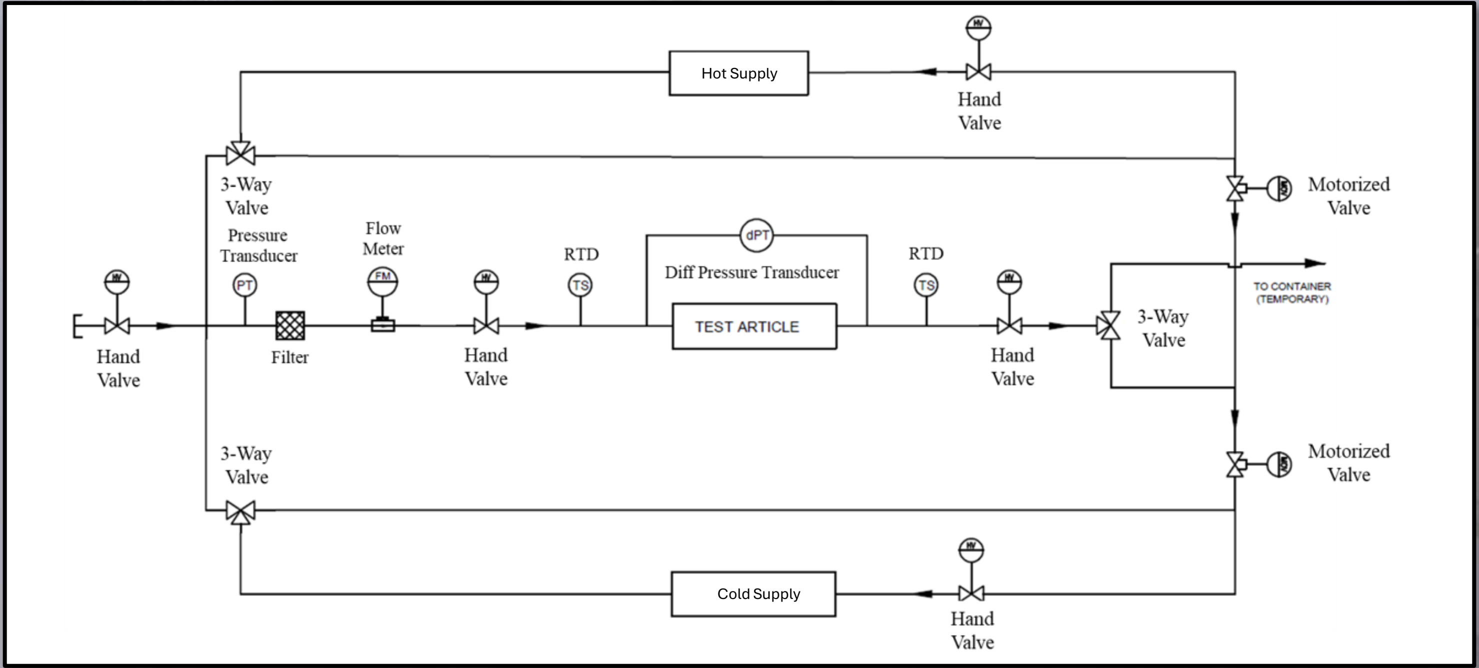
Early EC6 shell / tube prototypes

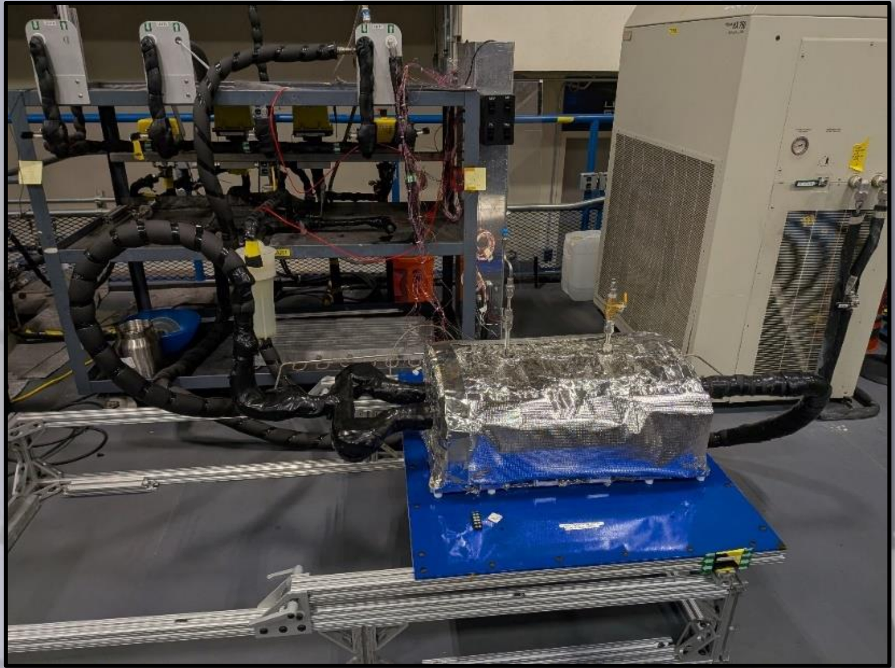




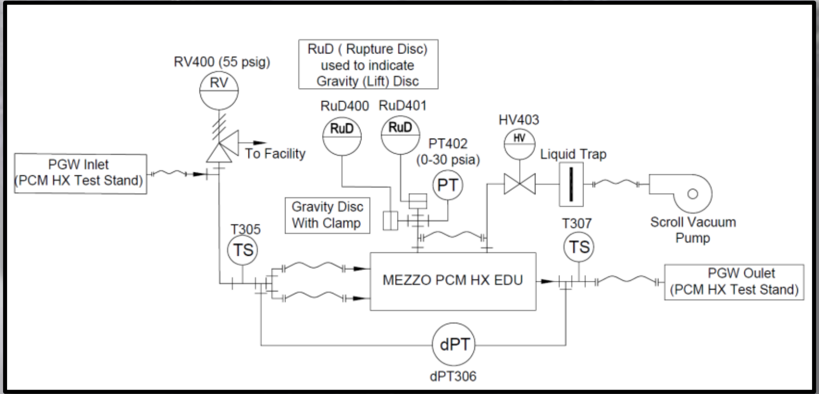
Mezzo SBIR Prototype

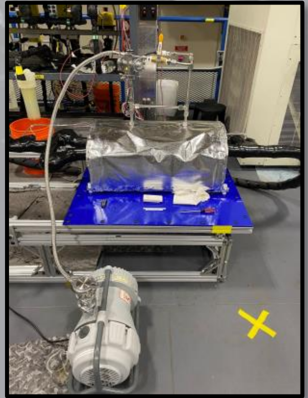
Thermal Capacitance Test Support Equipment





- Goal of PGW Loop
  - Emulate Orion “flight-like” conditions (flowrate, set temperatures, etc.)
- Goal of N-pentadecane-side hardware
  - Degas the n-pentadecane through multiple freeze-vacuum-thaw cycles to prevent localized pressure spikes seen on the ISS payload from 2015.
  - N-pentadecane is kept at reduced pressure during test to reduce re-introduction of dissolved gases and allow for headspace during thermal expansion





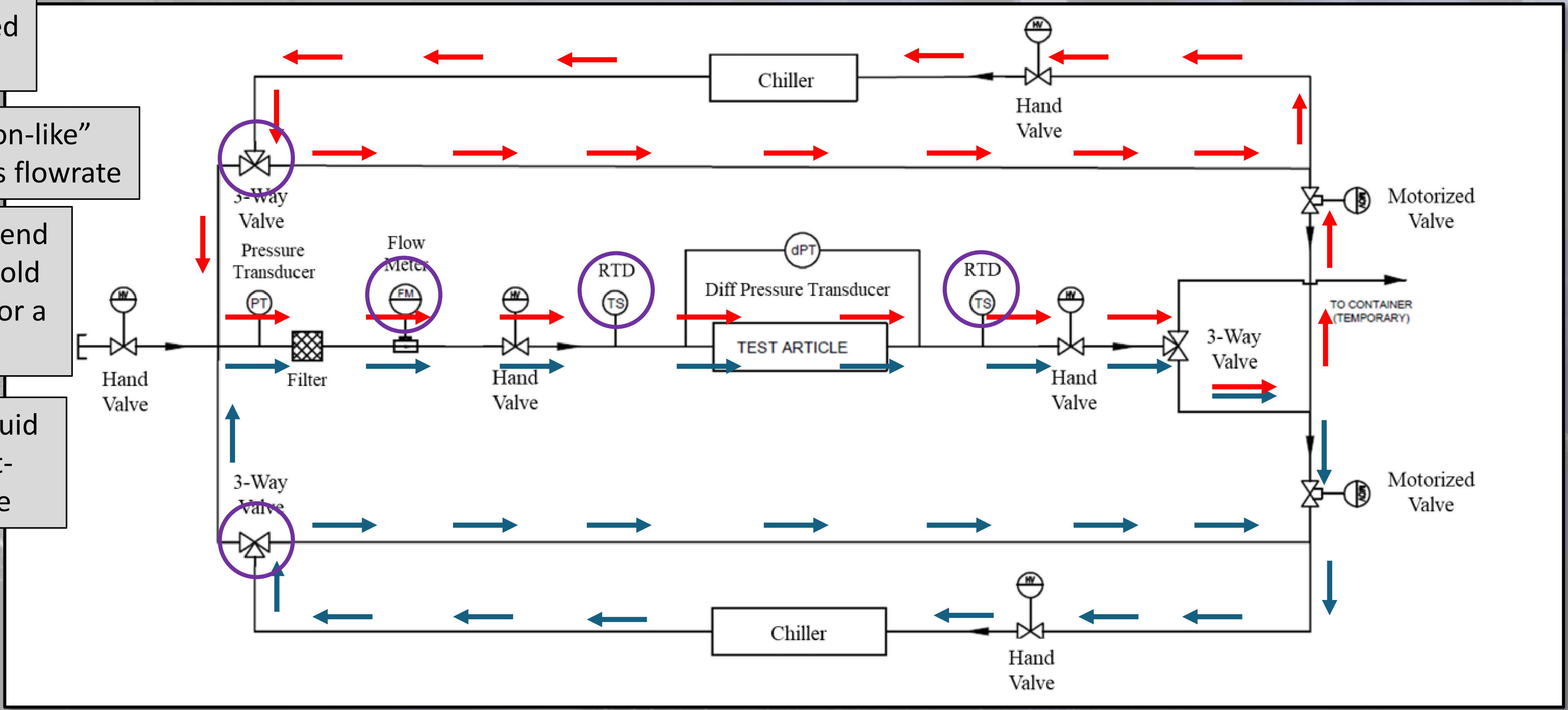
Thermal Capacitance Testing, Standard Operating Procedure

Circulate cold loop at desired "cold soak" temperature

Circulate hot loop at "Orion-like" PGW hot set-point and mass flowrate

Use 3-way mixing valve to send cold PGW through HX to "cold soak" and freeze the PCM for a desired amount of time

After cold-soak, send hot fluid through HX at desired set-temperature and flowrate



Measure heat capacitance from -2.7C to 11.1C (Orion requirement) at heat exchanger exit temperature

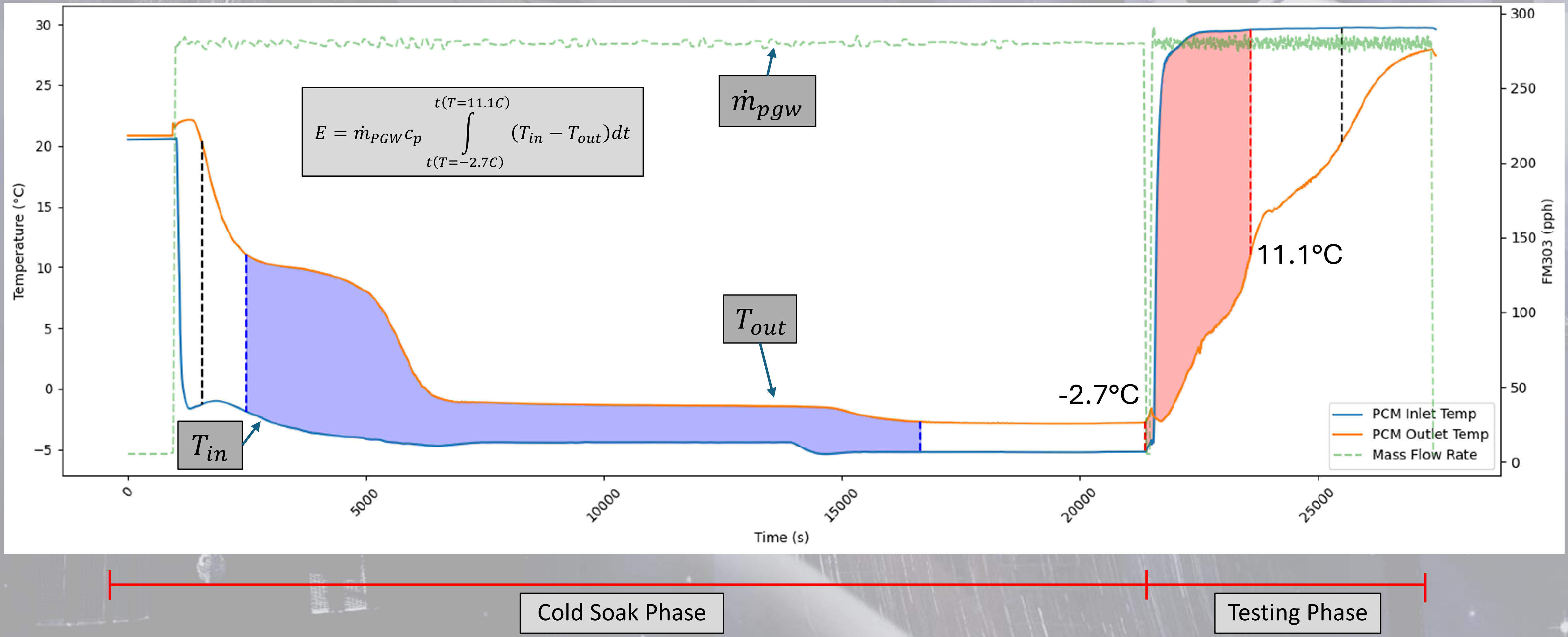
$$E = \dot{m}_{PGW} c_p \int_{t(T=-2.7C)}^{t(T=11.1C)} (T_{in} - T_{out}) dt$$

Thermal Capacitance Testing, Test Matrix

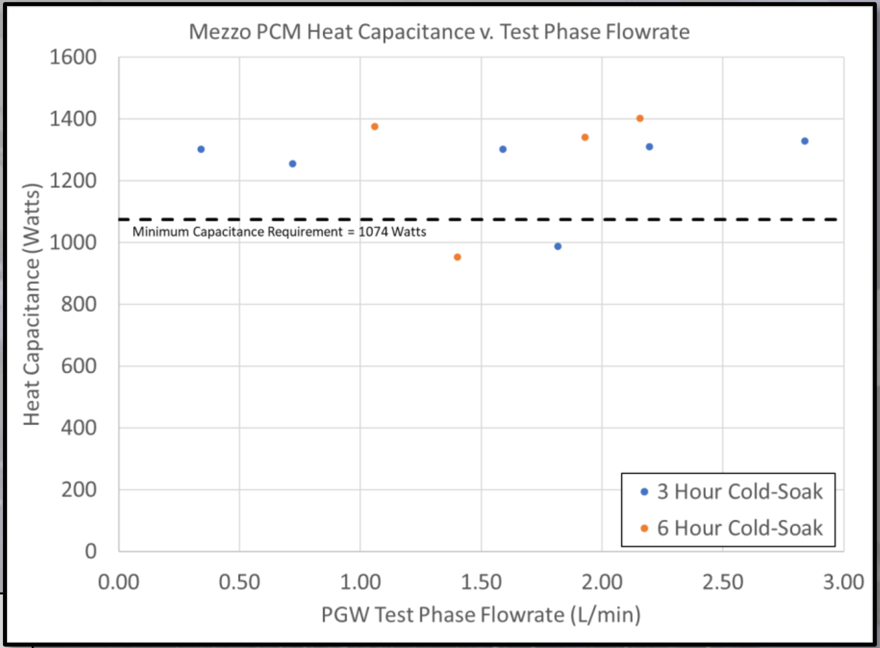
- Overall Testing Goal – Measure the heat storage of the Mezzo HX and compare to the Orion heat storage requirement (1074 Watts)
  - Additional Goal – Measure the effect of the following on heat storage:
    - Cold Soak Time (3hrs v. 6hrs)
    - Cold Soak Temperatures below (-6.5C, -10C) and above (-0.8C) second freeze point of n-pentadecane (-2.25C)
    - PGW Flowrate during test-phase (ranging from 0.34 L/min to 2.9 L/min)

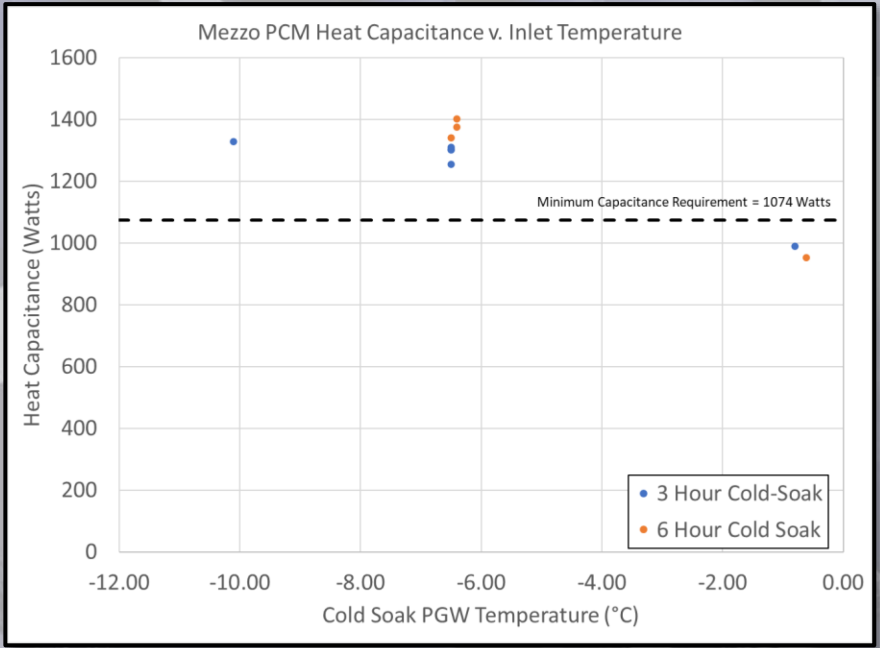
Test Point	PGW Inlet Temperature (°C)	Cold Soak Temperature (°C)	Cold Soak Time (hrs)	PGW Flowrate (L/min)
1	30	-6.5	6	1
2	30	-6.5	6	1.9
3	30	-6.5	6	2.2
4	30	-6.5	3	0.3
5	30	-6.5	3	0.7
6	30	-6.5	3	1.5
7	30	-6.5	3	2
8	30	-0.8	3	1.5
9	30	-0.8	6	1.5
10	36	-10	3	2.9

Thermal Capacitance Testing, Example Graph



Thermal Capacitance Testing Results





- The only test points which did not meet / exceed the 1074-Watt Orion requirement were the -0.8C cold soak test points
    - PCM requires second full freeze (-2.25C) to meet Orion requirement
- Cold soaking past 3-hours had very little effect on heat storage capacity.
- PGW Flowrate had negligible effect on heat storage capacity.

	Cold Soak Phase			Test Phase			
As Run Test #	Cold Soak Flow Rate (L/min)	Cold Soak PGW Temperature (°C)	Cooling Time (hr)	PGW Inlet Flow Rate (L/min)	PGW Inlet Temperature (°C)	Measured Capacitance (Watts)	Margin Against Requirement (Watts)
1	2.04	-6.40	6	1.06	29.40	1375.146542	301.5826495
2	1.82	-6.50	6	1.93	29.80	1339.976553	266.4126612
3	2.04	-6.40	6	2.16	29.60	1400.937866	327.3739742
4	2.12	-6.50	3	0.34	28.80	1300.996483	227.4325909
5	2.12	-6.50	3	0.72	29.20	1255.275498	181.7116061
6	2.08	-6.50	3	1.59	29.50	1302.168816	228.6049238
7	1.85	-6.50	3	2.20	29.90	1309.202814	235.6389215
8	1.89	-0.80	3	1.82	29.30	988.2766706	-85.28722157
9	2.54	-0.61	6	1.40	29.60	951.9343494	-121.6295428
10	1.97	-10.10	3	2.84	36.00	1327.960141	254.3962485

Conclusions and Current / Forward Work

- Conclusion: The Mezzo PCM Heat Exchanger met or exceeded the Orion heat storage requirement while decreasing the mass 17% when compared to the current one used on Orion.
- Forward / Current Work
  - Further flow through lab testing to bound performance amongst a wider range of test conditions (wider flowrate ranges, cold soak ranges, hot case temperatures, etc.)
  - Testing in TVAC to guarantee robustness in a similar environment. The current PCM on Orion is stowed in the ESM, which is exposed to space vacuum.
  - Further testing at multiple orientations to guarantee robustness to microgravity.
  - Shock and vibration testing to guarantee ability to survive launch loads.
  - Testing with different internal ATCS coolants to verify functionality across a multitude of spacecraft outside Orion.
  - Scaling the design up or down to meet varying vehicle heat storage requirements.

Thank you!

- NASA Management
  - Rubik Sheth
  - Paul Rathbun
  - Teresa Schurtz
  - Frederick Smith
  - David Westheimer
  - Paul Boehm
- EC Support
  - Eddie Uribe
  - Ethan Devine
  - Zac Colovos
  - Joseph Settles
  - Bryan Kanne
  - Yulia Meza
  - Marisa Markley
- Mezzo Technologies
  - Mat Mathews
  - Brett Guidry
- Lockheed Martin
  - Matt Gietzel
  - Nathan Wells
  - John Whitmore
  - Rahul Subramanian

EC6
Thermal Systems

References:

1. Lewis, R. Barido, C. Cross, and G. Rains, "Orion Multi-Purpose Crew Vehicle Active Thermal Control and Environmental Control and Life Support Development Status," in *42nd International Conference on Environmental Systems*, San Diego, CA, USA, 2012.

2. Creel, "Apollo Rover Lessons Learned: Applying Thermal Control Experiences on Apollo Lunar Rover Project to Rovers for Future Space Exploration," 2007. Available: http://history.nasa.gov/alsj/creel_lrv_experiences_alsj.pdf. [Accessed: Feb. 2, 2026].

3. Quinn, J. Stieber, R. Sheth, and T. Ahlstrom, "Phase change material heat sink for an ISS flight experiment," in *45th International Conference on Environmental Systems*, Bellevue, WA, USA, 2015