52nd International Conference on Environmental Systems



Hybrid Thermal Control System for Extreme Thermal Environments

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Outline

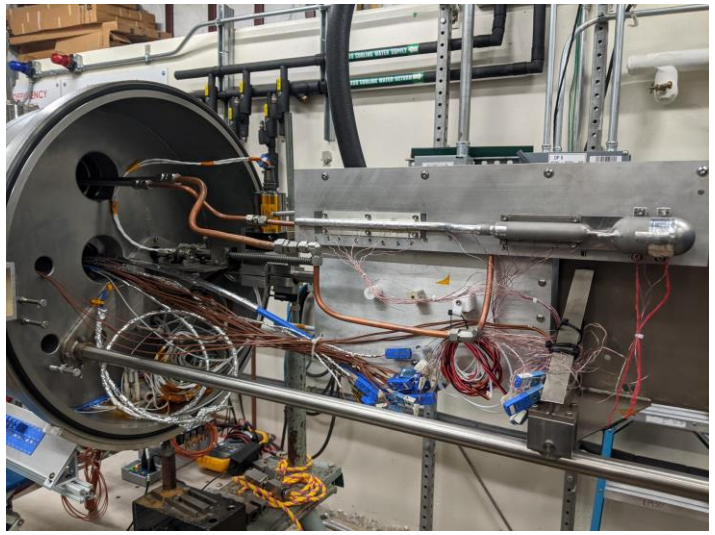
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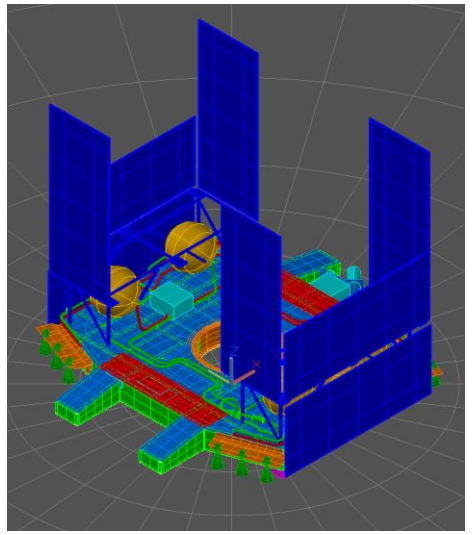
Introduction

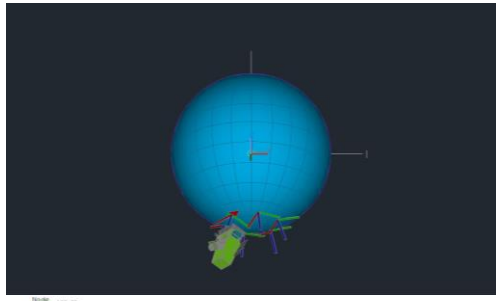
- Thermal engineer within the Space Systems Department at MSFC since 2017.
- Various projects supported from balloon-based telescopes to robotic Lunar landers.
- Recent focus on technology development and hardware testing.

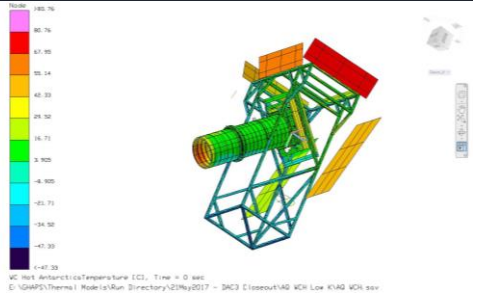
Special Shoutout to the Co-Authors!

- Kayla Daniel
- Kenton Roberts
- Greg Schunk
- Jeff Farmer





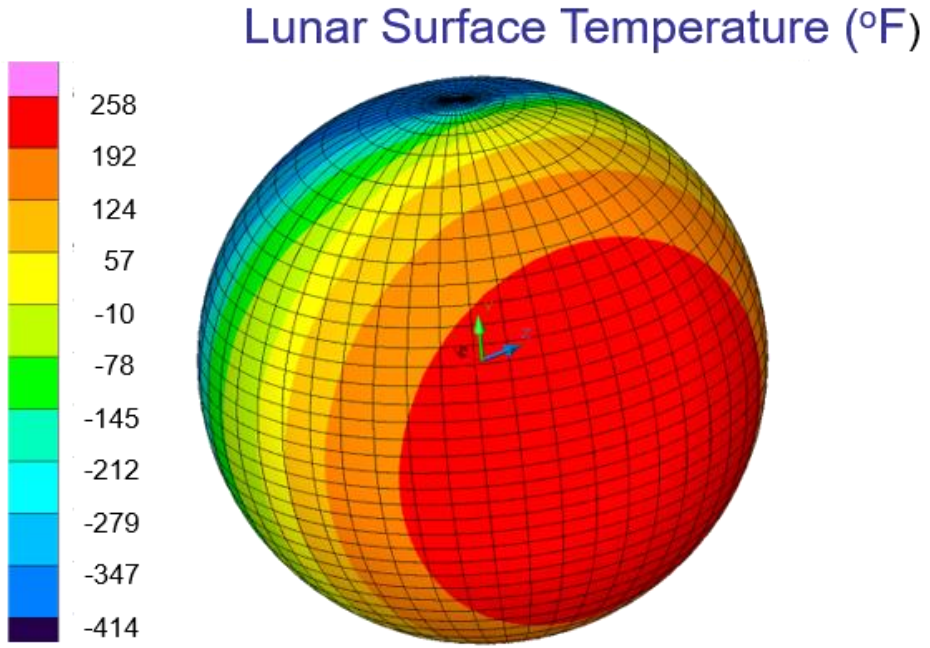






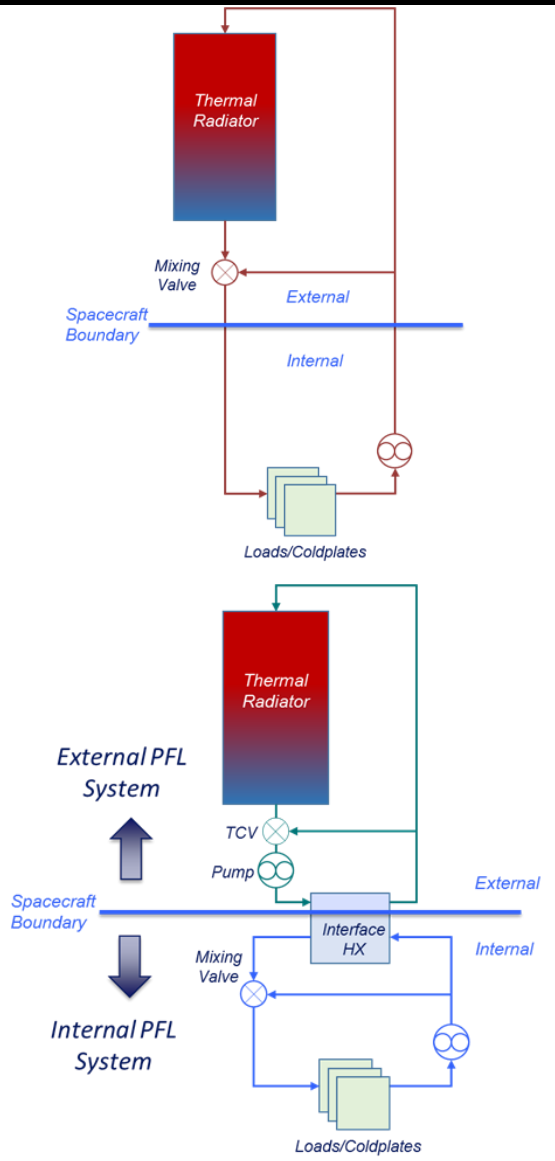
Background

- NASA's return to the moon brings many challenges, including issues with sustainable survival on the Lunar surface.
- One of the key challenges with sustainability is designing adequate thermal control systems that allow for surface systems to survive both during the day and the Lunar Night.
- At equatorial regions, the Lunar noon can be very hot, requiring systems with high heat rejection to the environment.
- At polar regions, such as those targeted by the first Artemis missions, the Lunar night temperatures plummet to -200 degrees Celsius or lower.
- Designing robust systems that allow surface systems to survive in these environments is critical to returning to the Moon in a sustainable fashion.



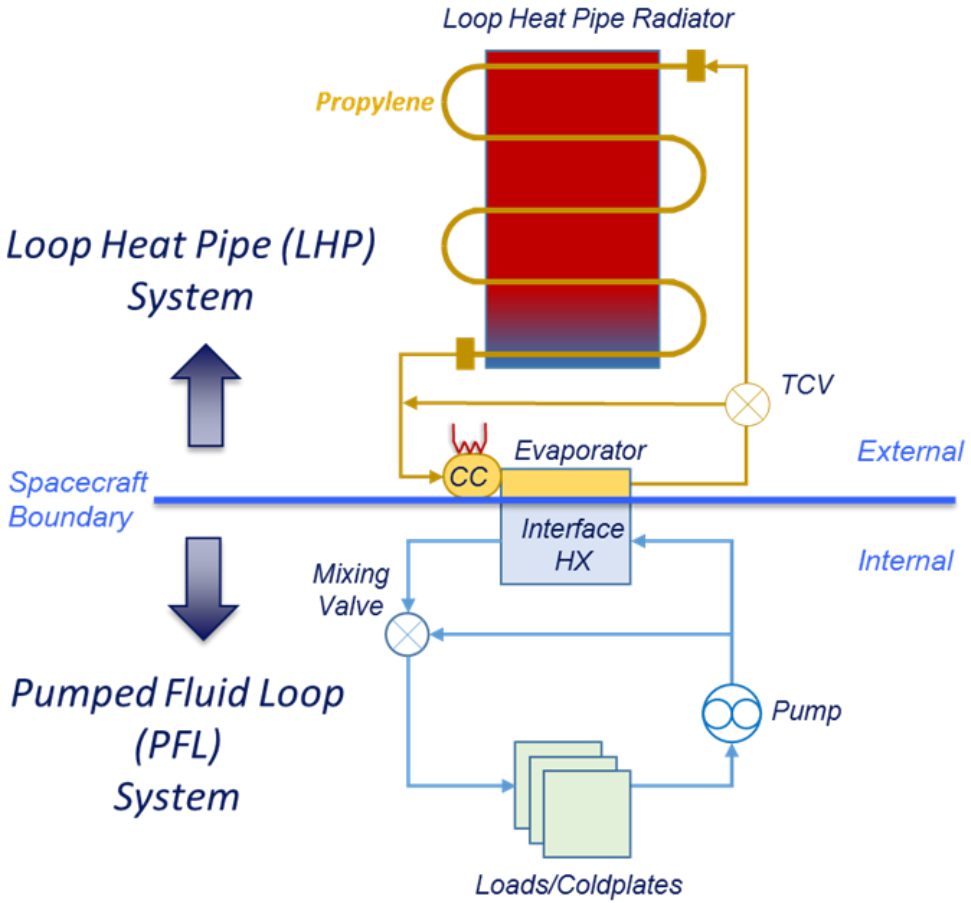
Motivation

- Single phase pumped fluid loop (PFL) based Active Thermal Control System (ATCS) architectures have traditionally been utilized to provide acquisition, transport, and rejection of heat from crewed spacecraft.
- Common design approach for the International Space Station (ISS), Space Transportation System (STS), Orion, and others has been to divide the TCS into two loops via a coupling through an interface heat exchanger.
  - Internal loop typically utilizes a crew friendly or non-toxic heat transfer fluid.
  - External loop working fluid typically chosen for freezing point and heat transfer performance.



Concept

- A hybrid thermal control system (TCS) approach provides a “best of both worlds” solution for extreme Lunar environments.
- Loop heat pipe (LHP) with passive thermal control valve (TCV) modulates the heat rejection and maintains evaporator temperature at setpoint.
  - Higher reliability and robustness compared to PFL radiator.
  - Mitigates issues with make-up heat during shadow periods.
- Traditional pumped fluid loop (PFL) collects waste heat from crewed volume and transports it to the LHP evaporator interface.
  - Provides traditional convenience, flexibility, and maintainability for crewed missions.

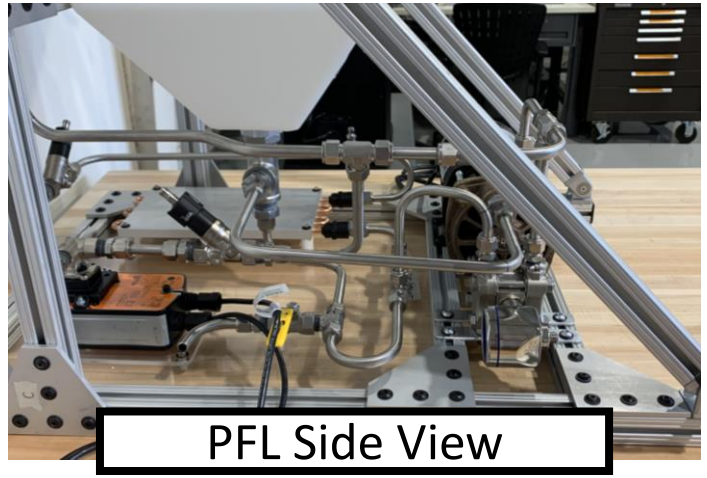


Pumped Fluid Loop

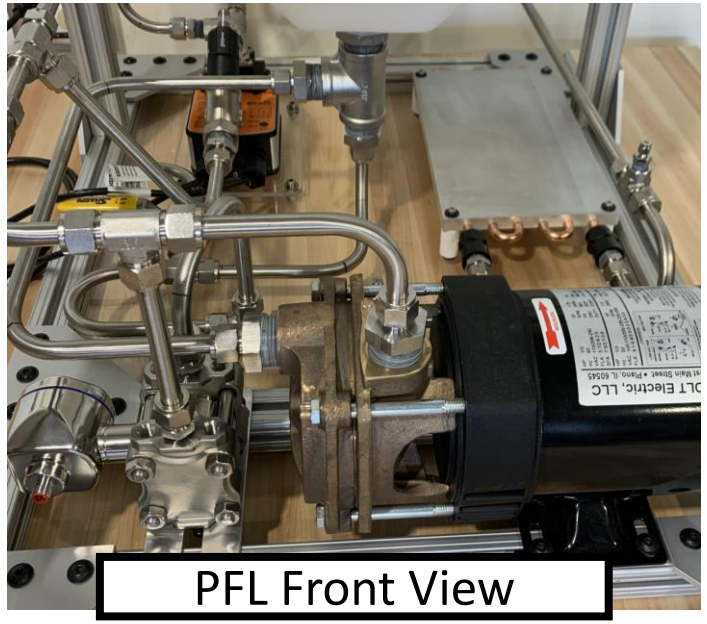
- Representative PFL built using commercial-off-the-shelf (COTS) components.
- Sized to provide up to 1000W of heat input, a nominal flow rate of 2 GPM, and differential pressure of 50 PSI.
- Utilized 30% solution of propylene glycol to water, which lowers the freezing point to -14°C.
- Controlled via LabVIEW virtual instrument.



PFL Control Panel



PFL Side View



PFL Front View

Loop Heat Pipe with Thermal Control Valve

- LHP radiator handles heat rejection from the spacecraft and provides several benefits over external PFL.
  - Propylene working fluid provides freeze protection in extremely cold environments.
  - Modular approach allows for multiple radiators to be used dependent on rejection needs.
  - Increased robustness compared to external PFL.
- TCV provides passive evaporator setpoint control and stops heat rejection as environment cools.
- Due to cost limitations, previously developed evaporator was incorporated into design.
  - Evaporator and radiator sized for 1000W of rejection.


LHP Radiator

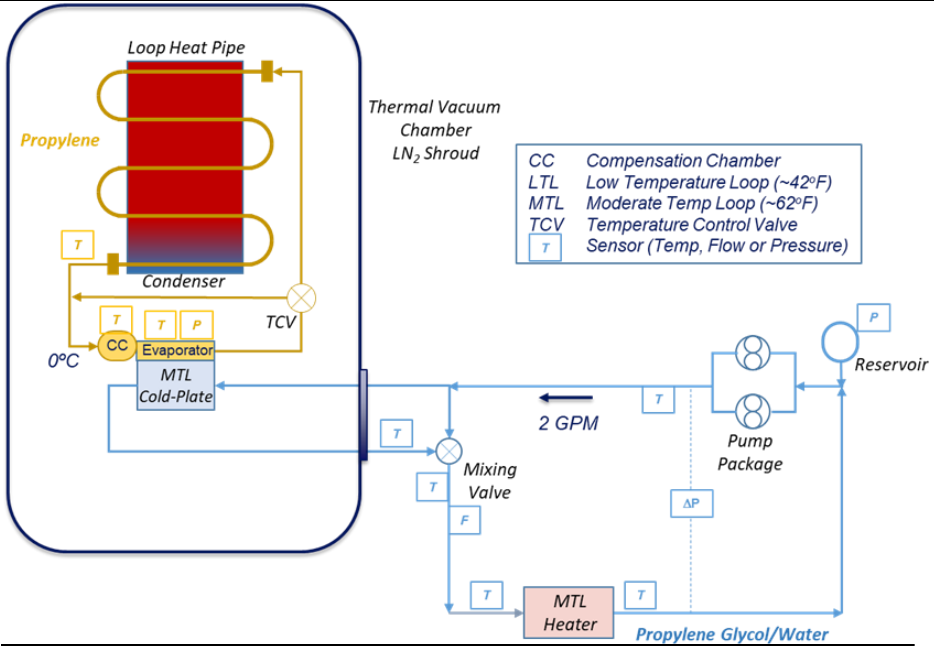

Evaporator

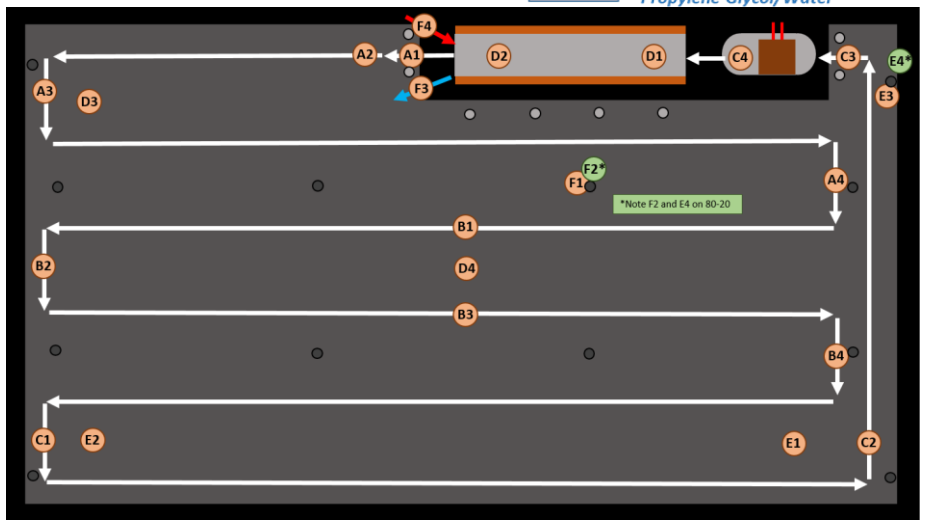

TCV


Compensation Chamber

Test Preparation

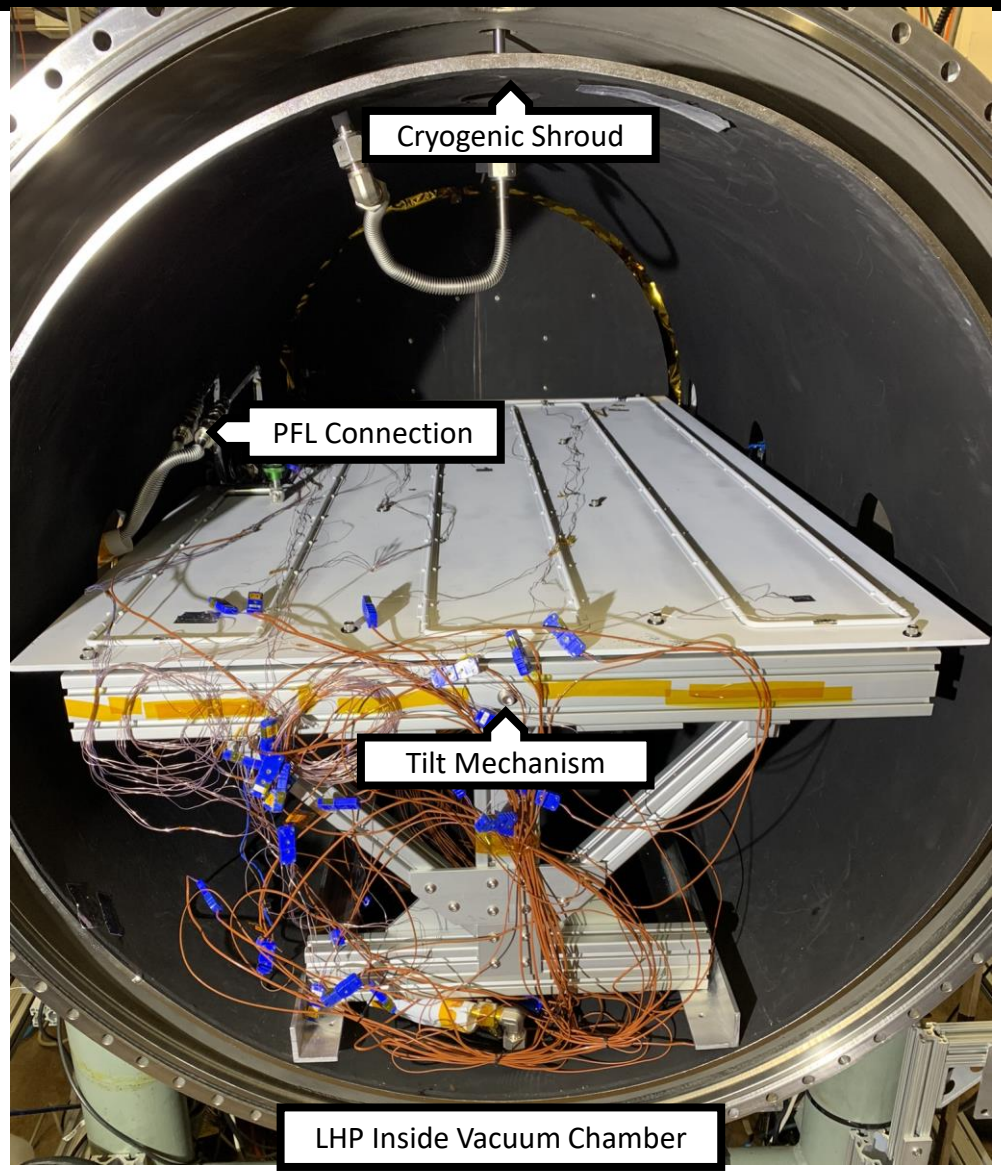
- The PFL was routed into the vacuum chamber wall utilizing a pair of fluid feedthroughs.
- A copper interface plate connected the LHP evaporator and the PFL cold plate.
- TCV charged to correspond to a 0°C setpoint.
- Thermal vacuum testing performed in the Space Environmental Effects (SEE) lab at MSFC.
  - Utilized their 4’ x 8’ cylindrical high vacuum chamber with liquid nitrogen shroud
- Instrumented with Type T thermocouples.





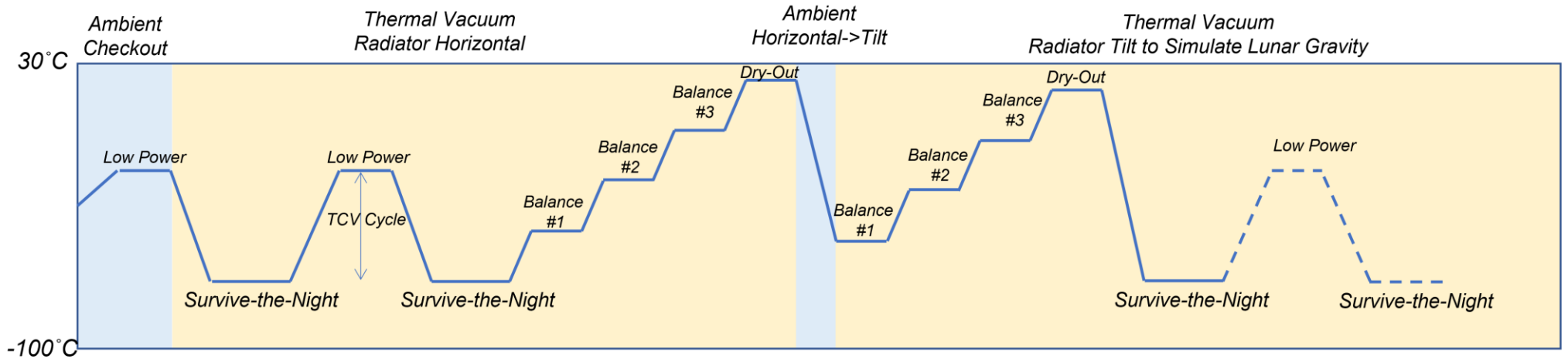
Test Preparation

- A frame was built out of 80/20 T-slotted aluminum extrusions to support the radiator in the vacuum chamber.
  - Frame allows the angle of the LHP to be easily changed without removing it from the vacuum chamber.
  - A 10° tilt, with the evaporator on the low side, simulates performance in Lunar gravity.



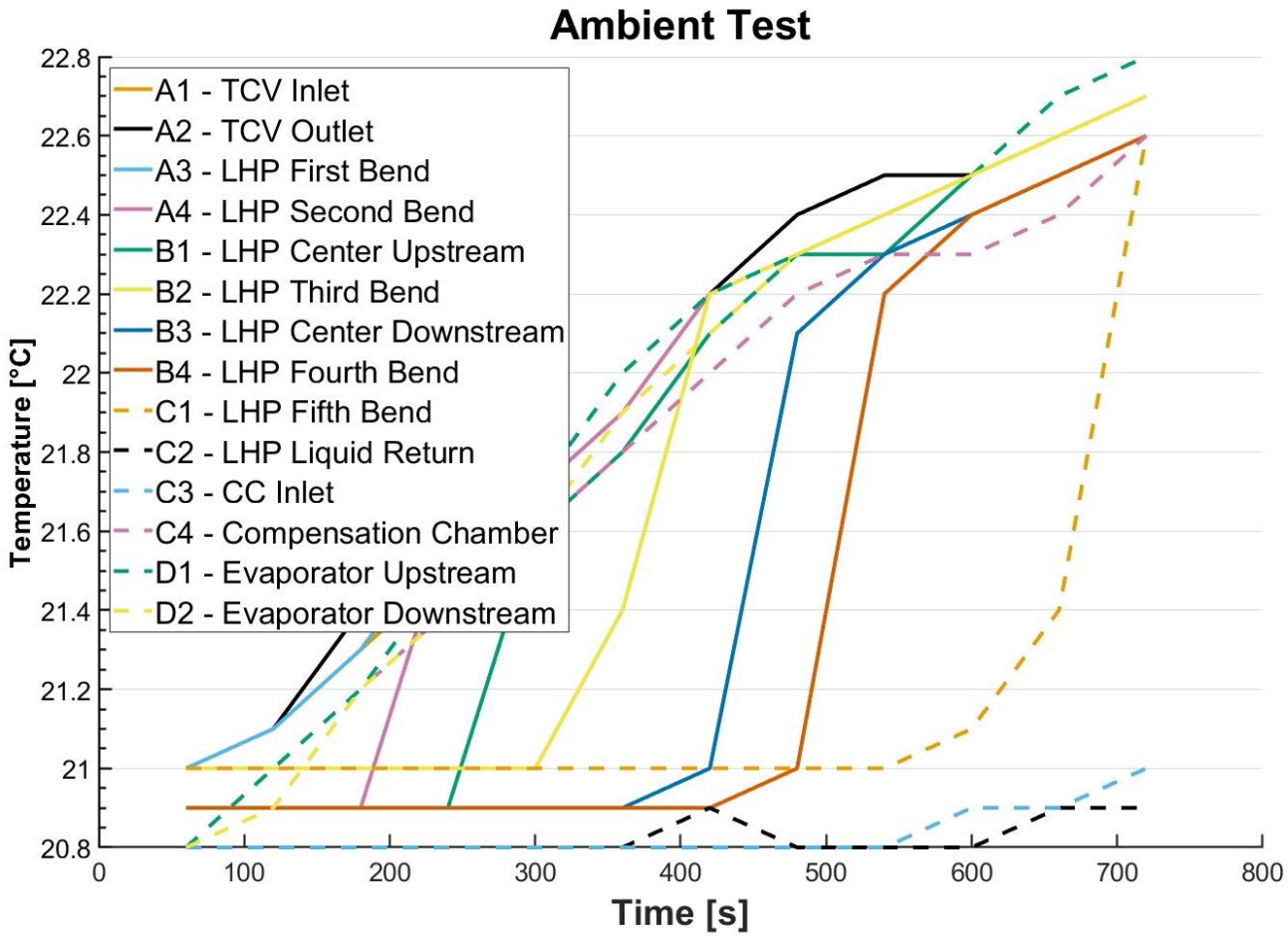
Test Plan

- Thermal vacuum (TVAC) testing was performed to demonstrate the feasibility of the hybrid TCS concept.
- Testing began with an initial cold period to highlight TCV protection of the PFL.
- Moderate power levels were applied to raise LHP out of survive the night conditions and allowing the TCV to open.
- Multiple thermal balance tests were performed at increasing power levels, up to the maximum power level of 1000 W.
- Radiator was then tilted to simulate Lunar gravity and tests were performed again to compare performance differences.



Ambient Checkout Testing

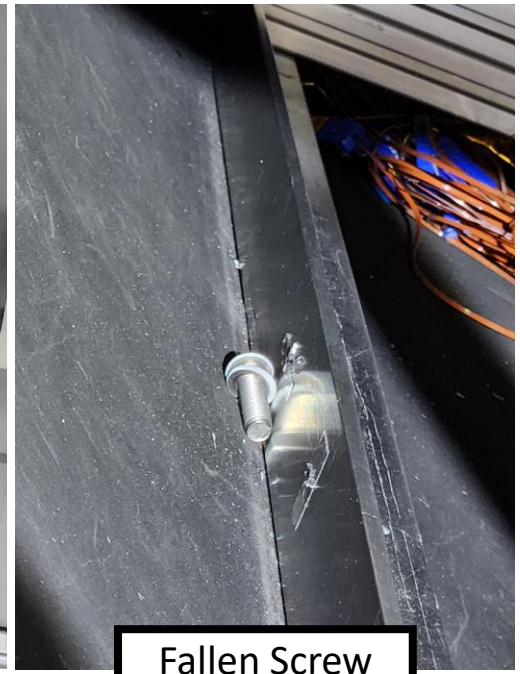
- Ambient testing with the radiatively cooled LHP was a challenge, so limited observations were obtainable.
- Over the approximately 10-minute duration of ambient testing, the LHP evaporator temperatures (TCs D1 and D2) continued to increase in temperature.
  - Not pictured are the thermocouples for the PFL, which quickly approached 30°C with just the waste heat input from the pump.
- The characteristic progressive temperature jumps throughout the condenser line (TCs A3 though C2) indicates the vapor front successfully moving through the two-phase region of the LHP.
  - This demonstrates that the loop successfully started up upon the application of heat to the evaporator.

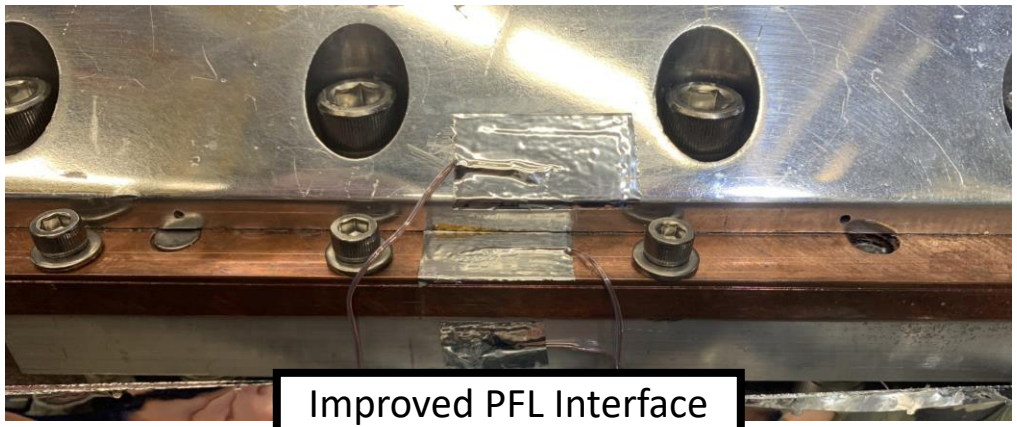


Test Challenges

- Initial attempts at thermal vacuum testing faced multiple issues.
- Upon reaching an initial steady state condition, it was observed that the deltaT across the PFL interface was very large – 30°C.
  - This indicates poor coupling to the copper spreader bar that connects the PFL to the evaporate.
- Clearly this deltaT was not suitable for a successful test, so the chamber was opened to investigate.
  - It was discovered that three of the four screws holding the copper spreader bar to the PFL interface plate had loosened, with the fourth completely backed out and sitting on the bottom of the chamber.
- This issue was remedied by match-drilling twelve additional holes through the copper spreader bar/PFL interface and installing cap screws with locking nuts.


Loose Screws

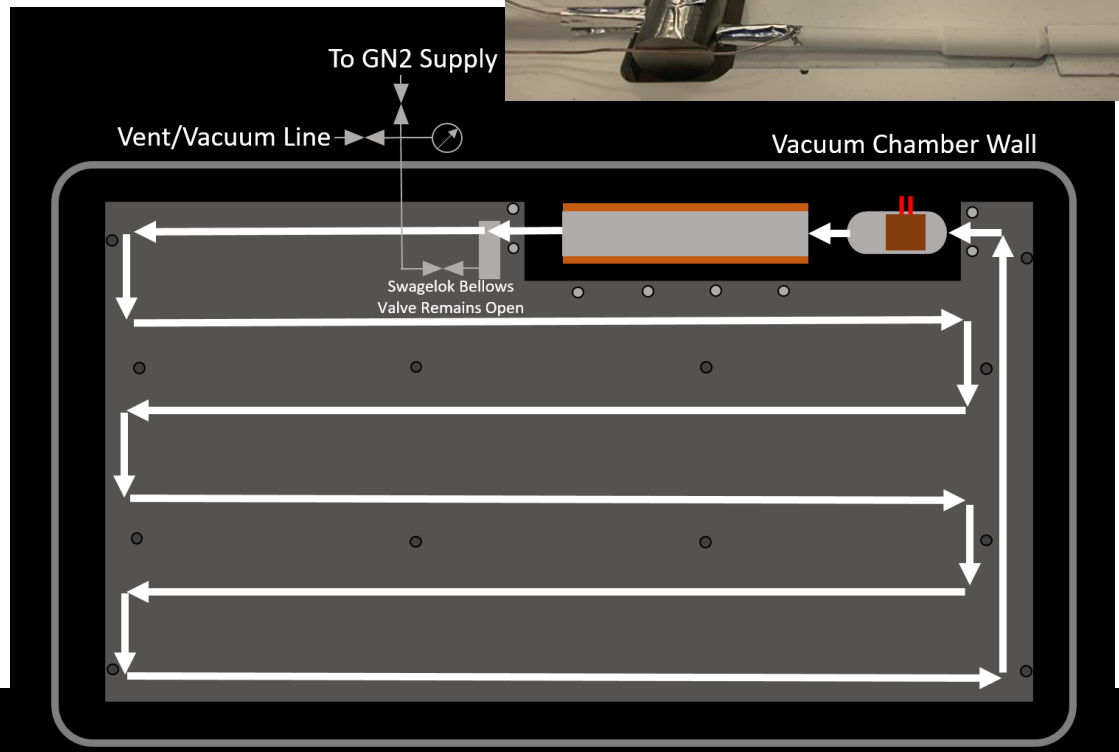

Fallen Screw


Improved PFL Interface

Thermal Control Valve Issues

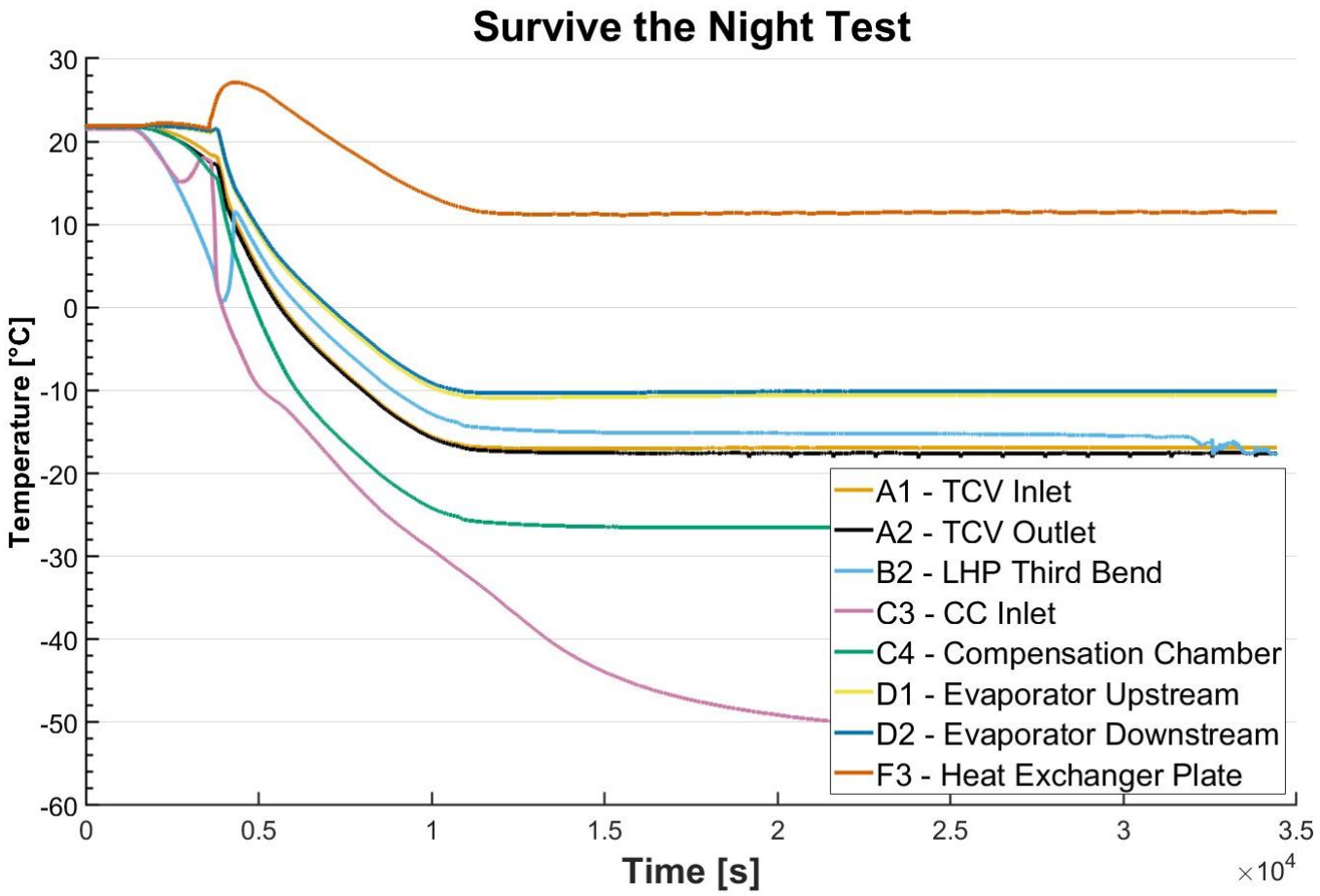
- The TCV also proved to be a learning opportunity.
- The initial thermal vacuum test resulted in LHP temperature significantly colder than anticipated, indicating the TCV was not operational.
  - Upon returning the chamber to ambient and checking the TCV pressure, it was discovered to be at 0 PSI.
  - A loose fitting on the bellows valve was determined to be the culprit.
- The second thermal vacuum test demonstrated TCV operation at a lower evaporator temperature than anticipated.
  - Discussions with ACT revealed that the TCV pressurization curve was created at ambient temperature and constant pressure.
  - In order to save time, rather than generating a new curve, a K-bottle was routed through an additional fluid feedthrough to maintain TCV pressure as the temperature changed within the chamber.





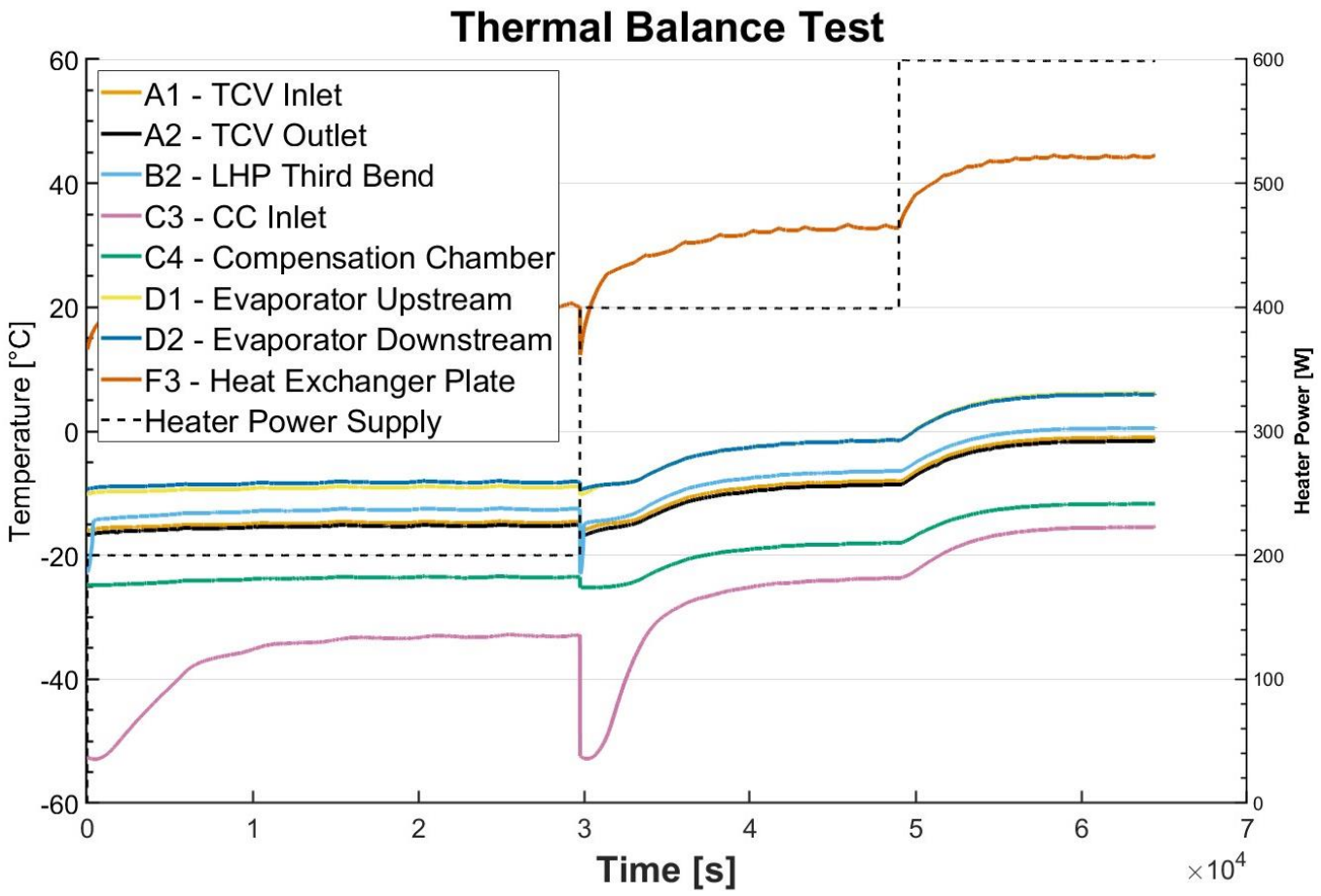
Test Results

- Integrated system testing was moderately successful. Several observations and lessons learned will aid future testing.
- Concept was successfully demonstrated by rejecting PFL waste heat with LHP radiator.
- TCV maintained evaporator temperature, protected PFL from freezing, during survive the night periods.
  - Pulsing visible in TCV outlet indicates short durations of TCV opening to moderate the LHP evaporator temperatures at the set point.



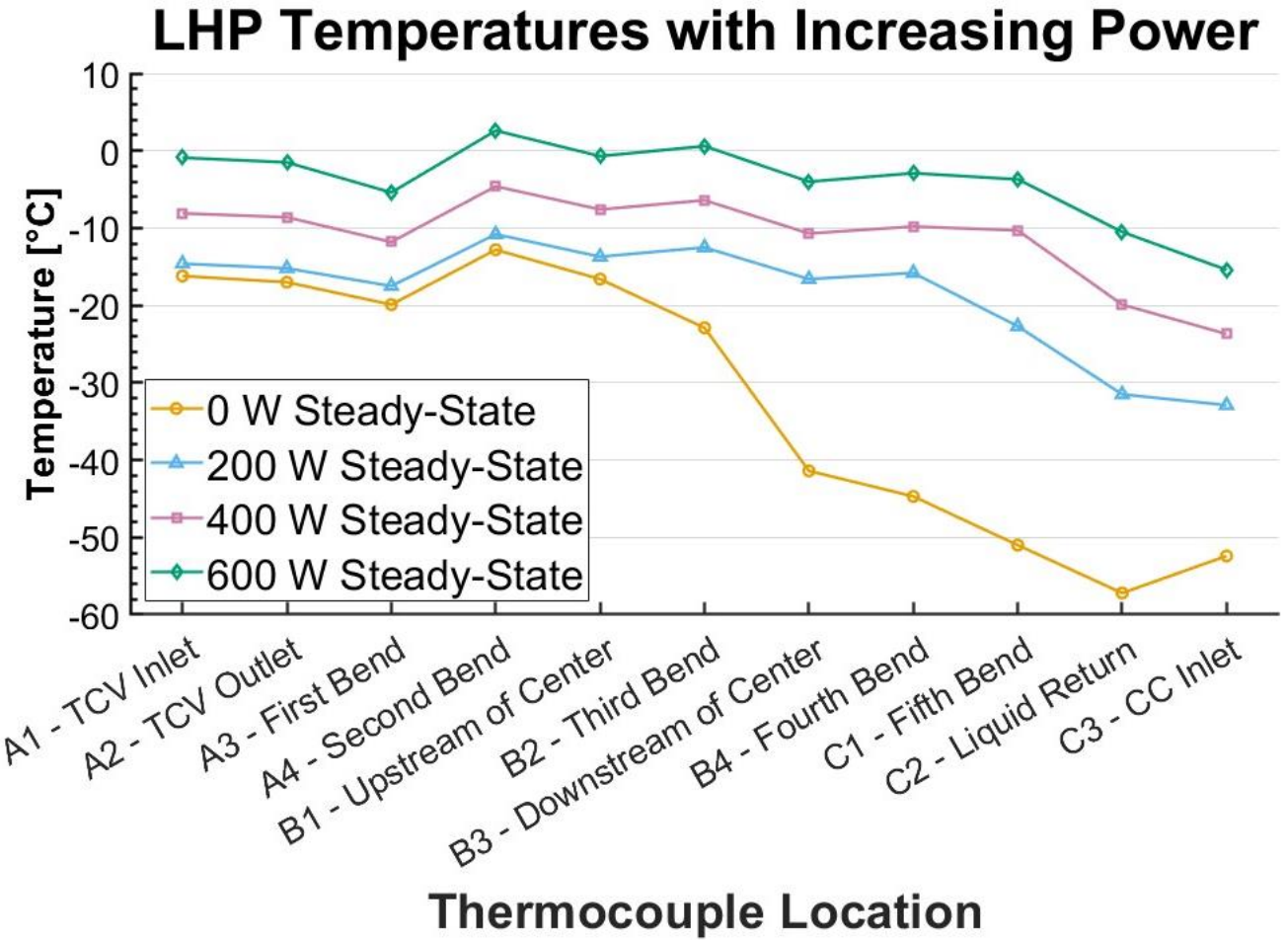
Test Results

- Thermal balance tests performed for heater set points of 0W, 200W, 400W, and 600W.
- At 0W and 200W the evaporator temperature remained constant at the TCV setpoint of -10°C.
  - At 400W and 600W the evaporator temperature rose, indicating the TCV was completely open to maximize power rejection.
- Steady state condition was a temperature change of no more than 0.5°C per hour.



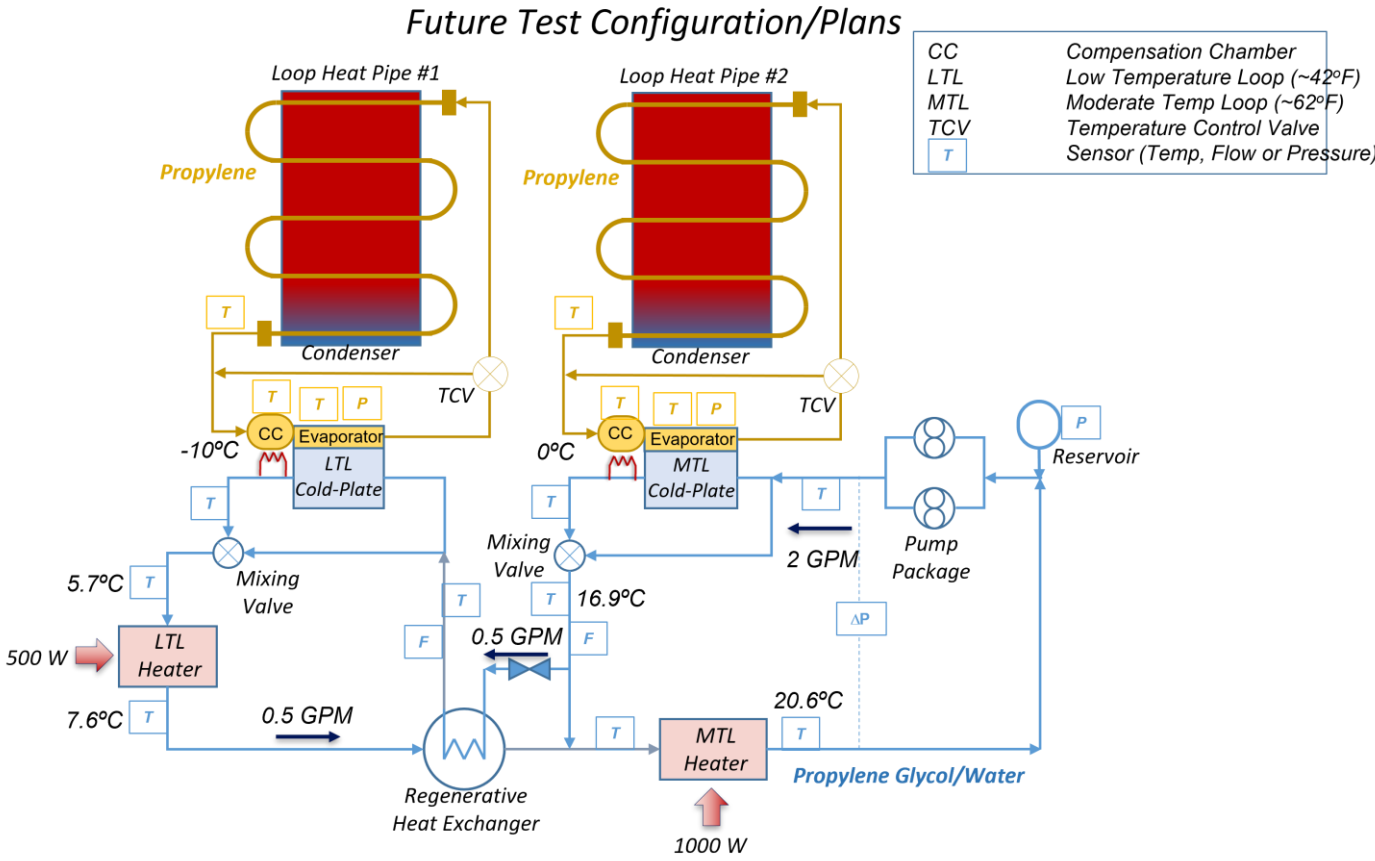
Test Results

- COTS pump unexpectedly provided significant (200 W) waste heat.
- Large delta-T across the PFL to LHP interface resulted in lower performance (800 W max) than anticipated.



Next Steps

- Internal funding opportunities are being pursued to continue developing this concept based on the lessons learned.
- The next iteration will include a second LHP in order to show the modularity of the concept and extend it to more realistic rejection values.
  - Comparing the performance of a VCHP configuration is also being discussed.
- Optimizing interface between LHP evaporator and the PFL is critical.
  - Pursuing including PFL channels within LHP evaporator.



Acknowledgements

- Special thanks to Advanced Cooling Technologies (ACT) for fabricating the Loop Heat Pipe and providing troubleshooting support during testing.



- This effort would not have been possible without the support of the Space Environmental Effects group at MSFC. Specifically, the assistance of Erin Hayward, Todd Schneider, Jason Vaughn, and Patrick Lynn was invaluable.

- Additional thanks is due to the Habitation Systems Development Office at MSFC for providing supplementary funding and FTE support.

Questions?



Contact Me!
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