Hybrid Thermal Control System for Extreme Lunar Environments

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Background

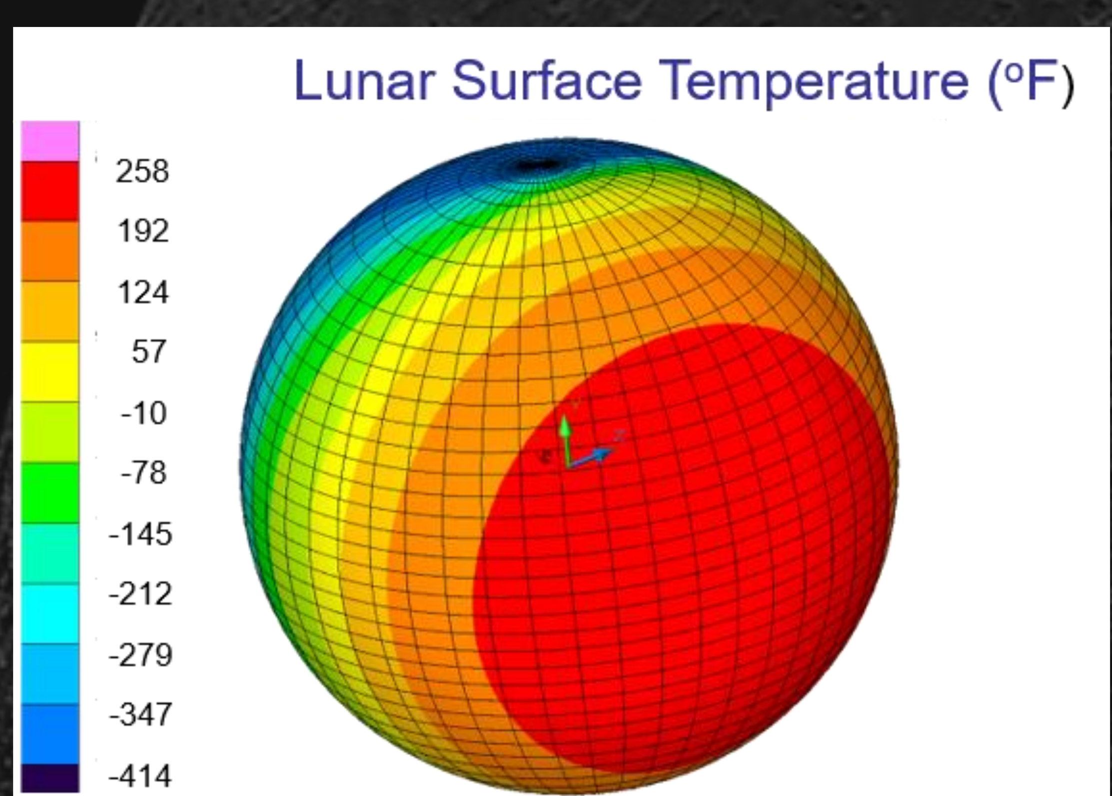
NASA's return to the moon brings many challenges, including issues with sustainable survival on the Lunar surface.

- 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.

The extreme thermal environments on the Lunar surface are a challenging design space for thermal engineers.

- 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 return to the moon, 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.



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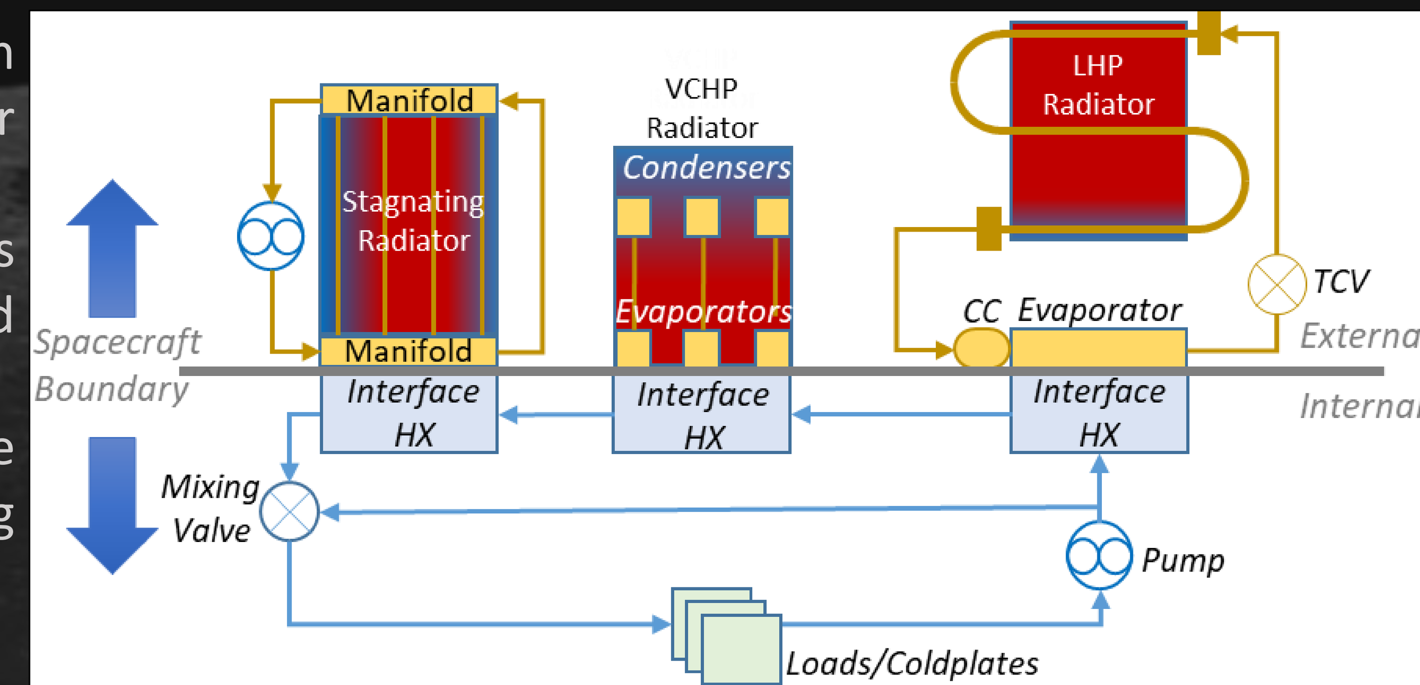
Concept

A hybrid thermal control system (TCS) approach provides a "best of both worlds" solution for extreme Lunar environments.

- Traditional pumped fluid loop (PFL) collects waste heat from crewed volume and transports it to the interface heat exchanger.
- Advanced radiator rejects heat to space during the Lunar day while passively turning off during Lunar night to conserve energy.
- Multiple radiator concepts being studied.



FY23 TIP

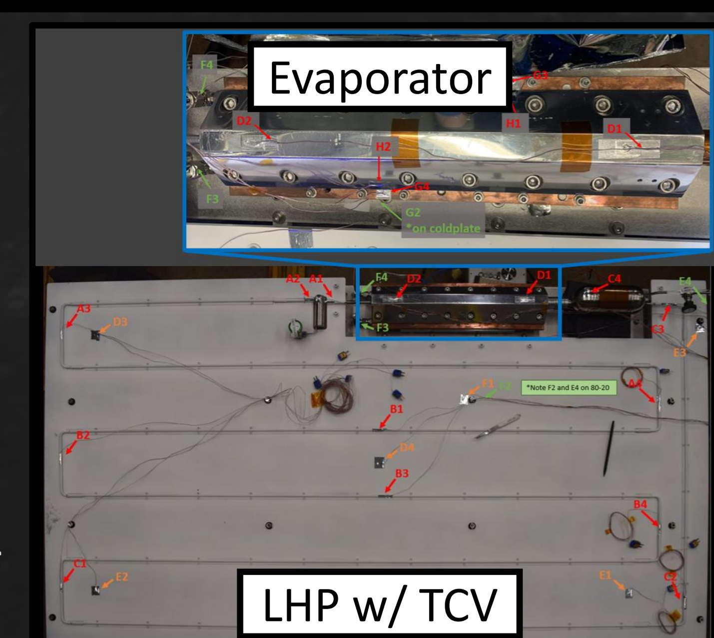
Hardware

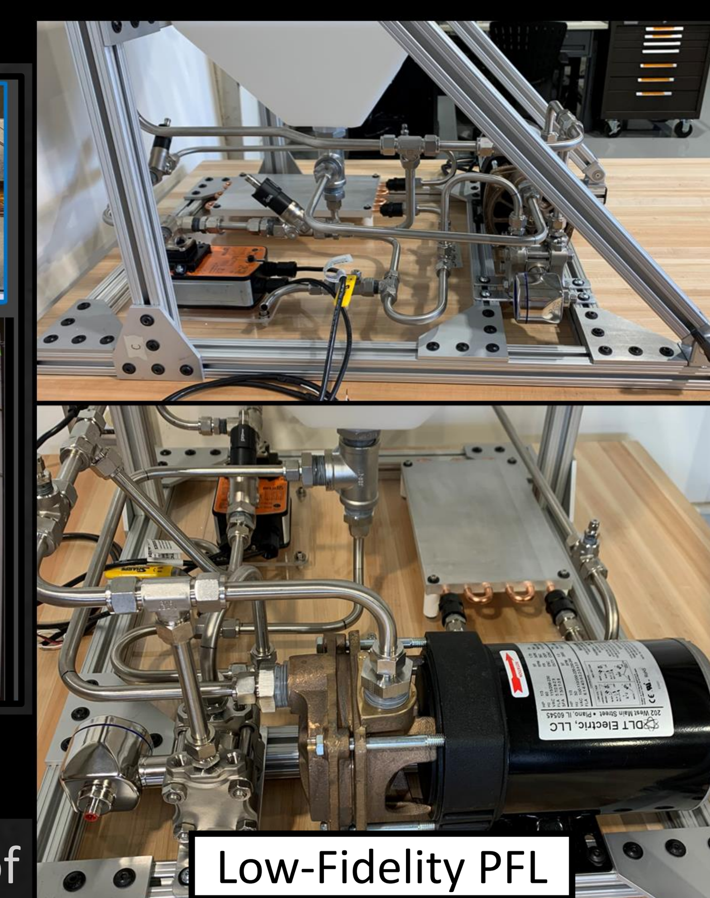
Loop heat pipe (LHP) radiator handles heat rejection from the spacecraft.

- Thermal control valve (TCV) provides passive evaporator setpoint control and stops heat rejection to radiator as environment cools.

Internal PFL maintains system temperatures and collects waste heat.

- Low-fidelity PFL built using industrial COTS components to simulate up to 1000 W of waste heat.



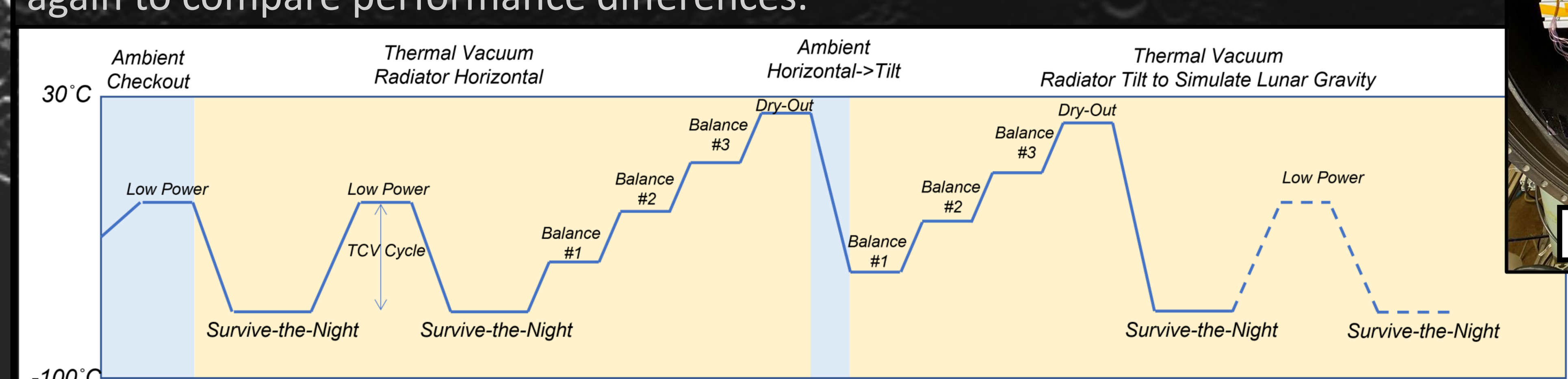


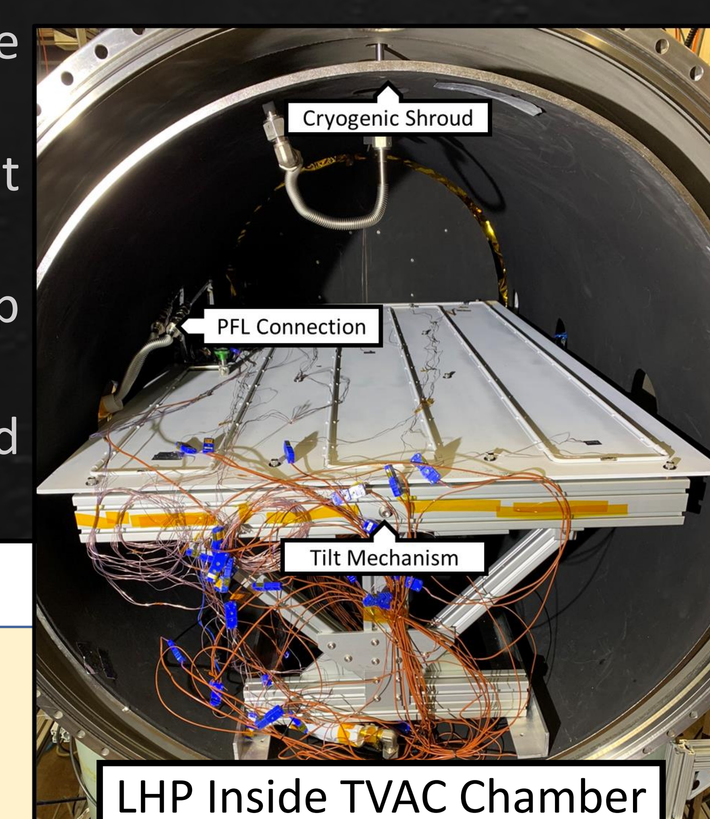
Testing

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 1000W.

Radiator was then tilted to simulate Lunar gravity and tests were performed again to compare performance differences.





FY24 TIP

Several lessons learned from FY23 TIP are being implemented in a follow-on TIP effort for FY24.

- Higher-fidelity PFL being fabricated to mitigate issues with industrial pump adding 200 W of unexpected waste heat to system.
- Higher-fidelity PFL being sized to provide true 1000 W of waste heat, whereas the low-fidelity PFL only provided 800 W in application.
- Advanced interface heat exchanger being developed to reduce the large delta-T observed in FY23 hardware testing.

Additional radiator concepts being explored in addition to LHP+TCV radiator.

- Stagnating radiator allows working fluid to safely freeze within tubes, stopping the rejection of heat to the environment.
- Single-phase serpentine radiator, potentially providing higher performance over traditional manifold radiator.
- Variable Conductance Heat Pipe (VCHP) radiator providing passive shut down with additional redundancy over other concepts (future effort).

Next Steps

Currently working through hardware design and fabrication for system components.

- 3D printed LHP (3DP-LHP) with TCV to be fabricated by Advanced Cooling Technologies (ACT); waiting on SBIR contract to be finalized.
- Stagnating and single-phase radiators under design and will be fabricated at MSFC during summer 2024.
- High-fidelity PFL under design and will be fabricated at MSFC during summer 2024.

TVAC testing of new system scheduled for fall 2024!

Partnership

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ACT has been a long-standing partner with MSFC and fabricated the LHP for the first effort. They are also fabricating the LHP for the second effort.