Volatiles Investigating Polar Exploration Rover (VIPER) Thermal Management System (TMS) Design, Development, & Testing

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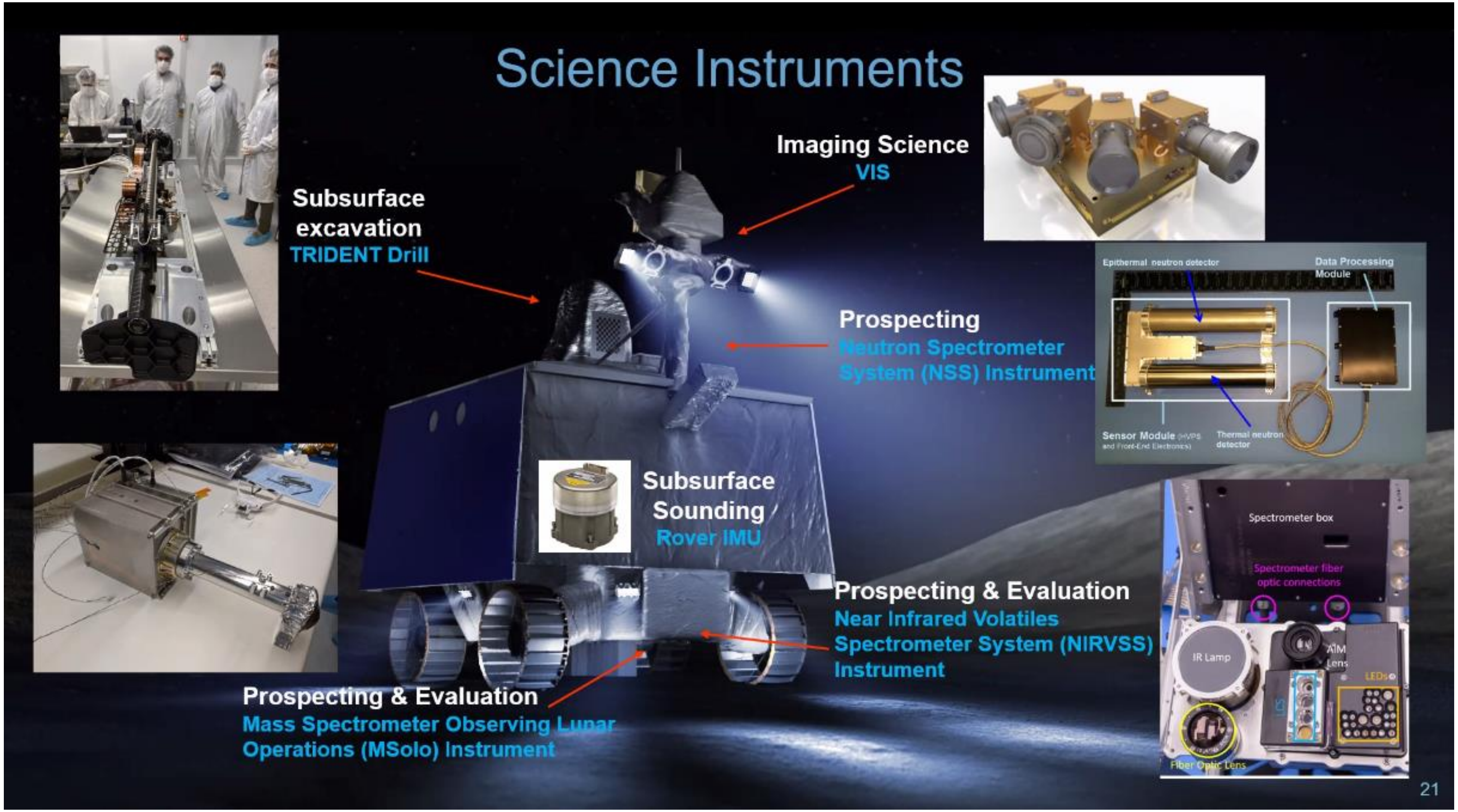
Outline

- ACT Involvement
- Mission Context
- TMS Challenges
- General TMS Approach
  - Main TMS Subsystems
- LHP With TCV - Concepts – Viper main novelty
- Design Process Overview
  - Design LHP
  - Design Heat Spreaders
  - Design Quarter Model
- Build and Testing
- Summary and Current Status

Mission Context

- What is it?
  - Lunar rover to south pole of moon
- Why?
  - Characterize water and other volatiles
    - In lunar cold traps & regolith
    - Understand their origin
  - Data to evaluate potential in-situ resource utilization
    - Where is the water and how much is there?

Mission context



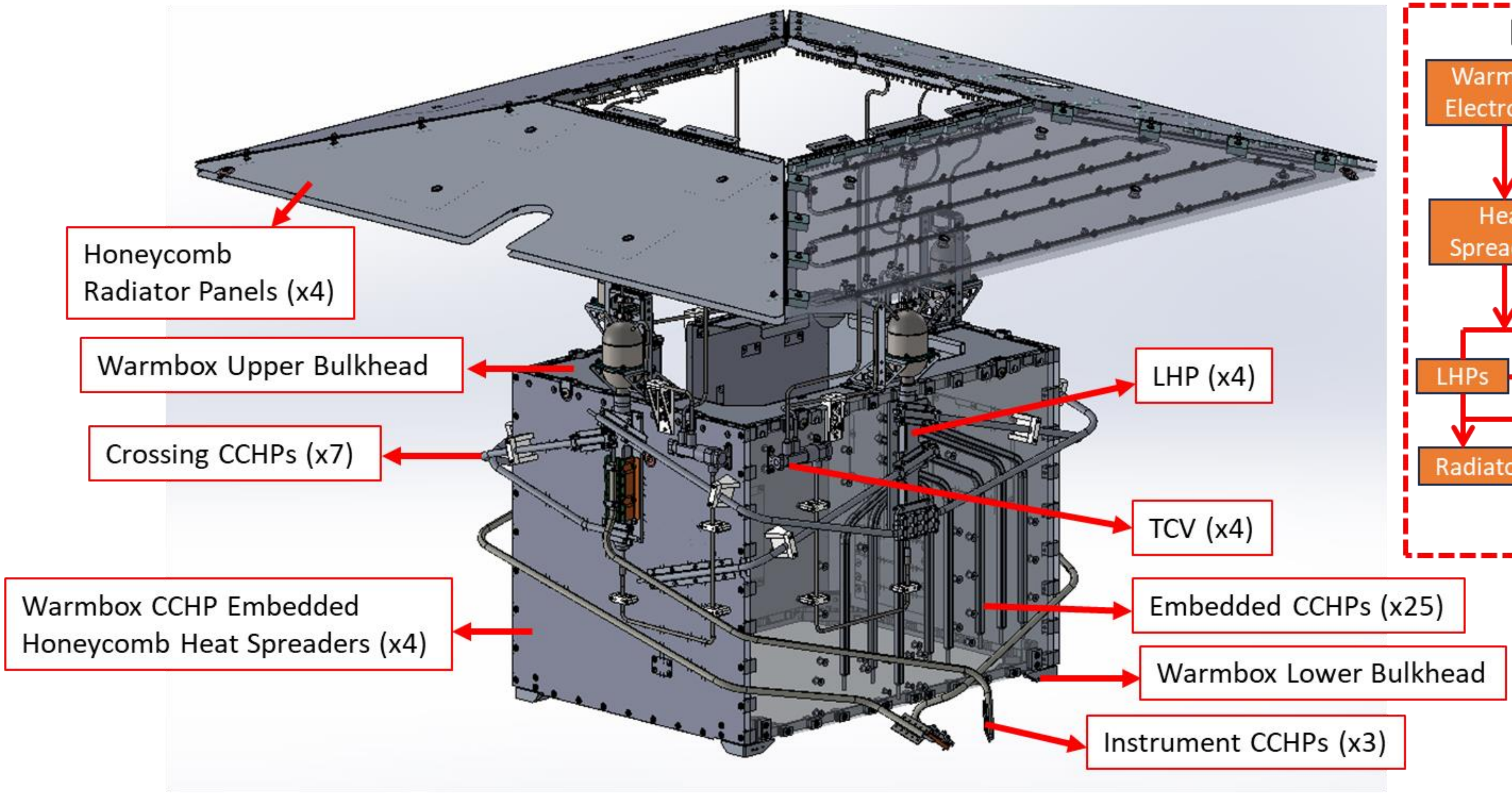
TMS Challenges

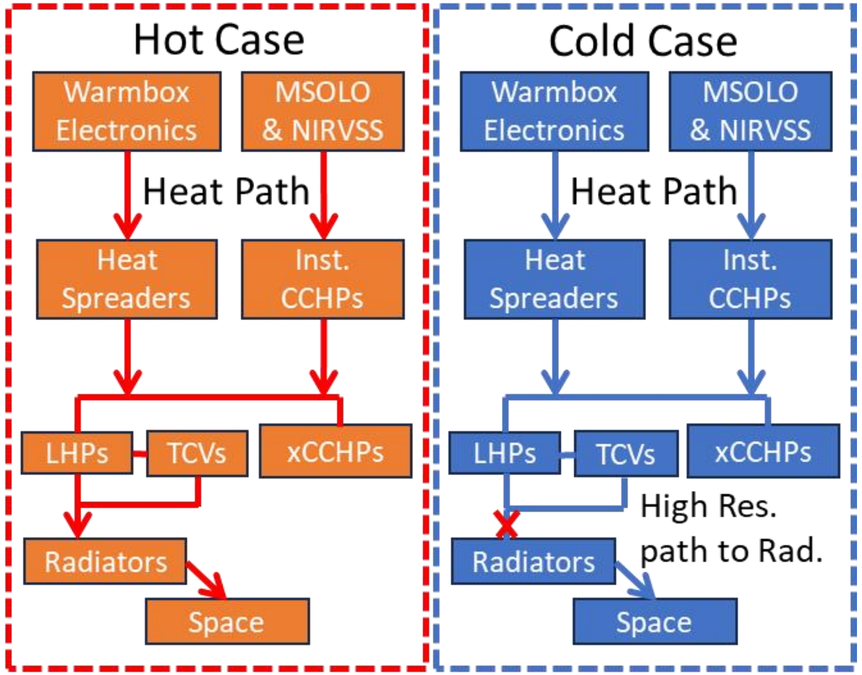
- Solar powered rover on south pole
- ~500° F temperature swing between day & night
- Lunar day is 14 Earth Days
  - 14 straight days of driving around doing science
  - Need to reject heat in high solar loading
- Lunar night is also 14 Earth Days
  - Need to operate over multiple Lunar day/night cycles
    - Big rover with ground to cover!
    - Lunar Night Survival
  - Need to protect cold sensitive components from “freezing”
  - Make sure components that will see cold temperatures can survive

General TMS Approach

- Put temperature sensitive components together in a “warm-box”
- Survival heaters to maintain warm-box temperature
- Have variable conductance thermal path to radiators
  - ON during daytime for performing science and rejecting heat efficiently
  - OFF at night (in lunar shadow) to minimize heater power and consequent battery mass needed
- Use passive thermal control devices to provide the necessary heat spreading/transfer in order to further minimize battery mass needed

Main TMS Subsystems





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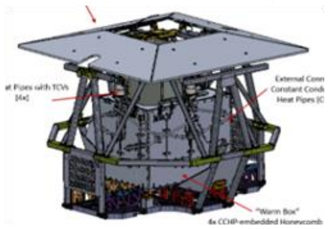
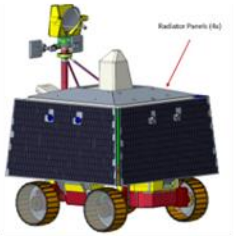


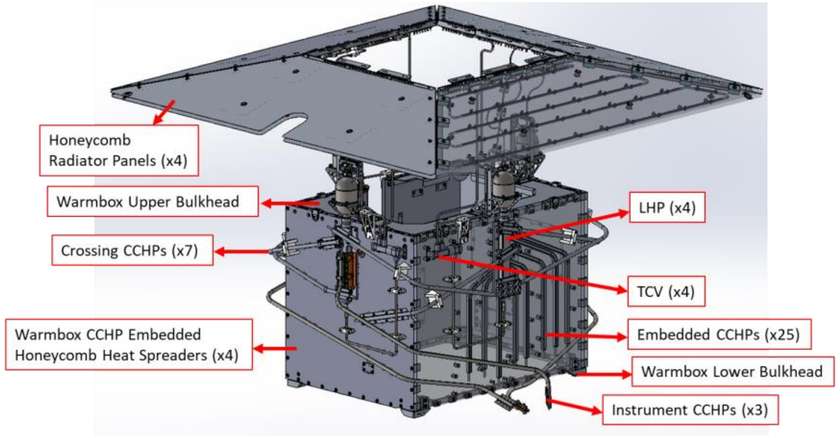
Rover Integrated



VIPER Thermal Management System (TMS) with Subsystems Labeled and the General Purpose of Each

Main TMS Subsystems

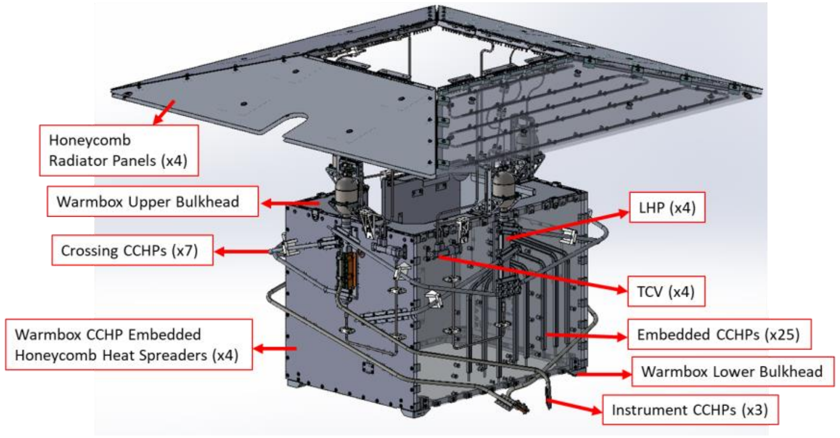
1. Loop Heat Pipes (LHPs) integrated with Thermal Control Valves (TCVs)
   - Main novelty of the Viper TMS – TCVs used before with pumped loops
   - QTY 4 for redundancy
   - Both passive devices
     - LHP operates with low conductance to radiators when heat applied
     - TCV cycles (switches between 2 outlets) based on temperature
       - Can be selected for various operating temperatures
   - Rigid tubing for transport lines can be designed to allow end/end displacements
   - Capable of providing a high turn-down ratio
     - ON Conductance >> OFF Conductance
     - Details on later slides



Main TMS Subsystems

2. Aluminum Honeycomb Panel Radiators

- Each LHP has its own dedicated radiator panel to which the condenser is mounted
- Main link to the ultimate heat sink – space – via radiation from "white" high emissivity, low absorptivity paint
- Aluminum honeycomb for mass conscious structural support
- Need to utilize materials that can survive near cryogenic temperatures during Lunar Night
  - Survival heaters designed to be capable of keeping radiators only above/at a cold ~100K such that the fluid in the LHP doesn't freeze
  - Relied on flight heritage potting compounds, film adhesives, etc.

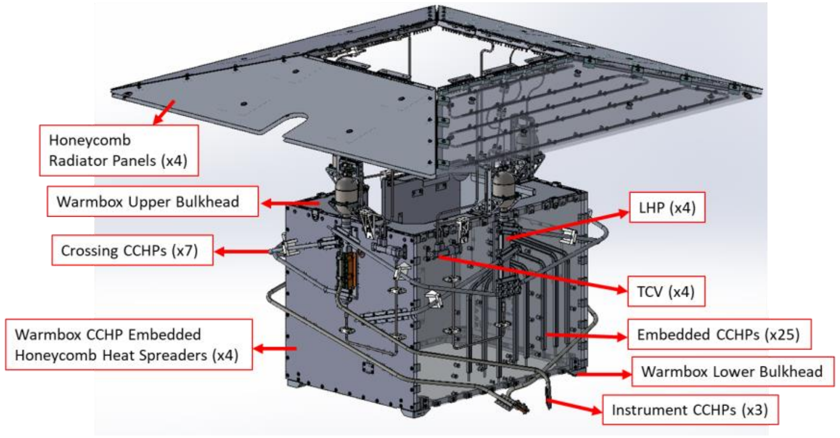


Main TMS Subsystems

3. Aluminum Honeycomb Panel Heat Spreaders (HS) with Embedded Aluminum-Ammonia Constant Conductance Heat Pipes (CCHPs)

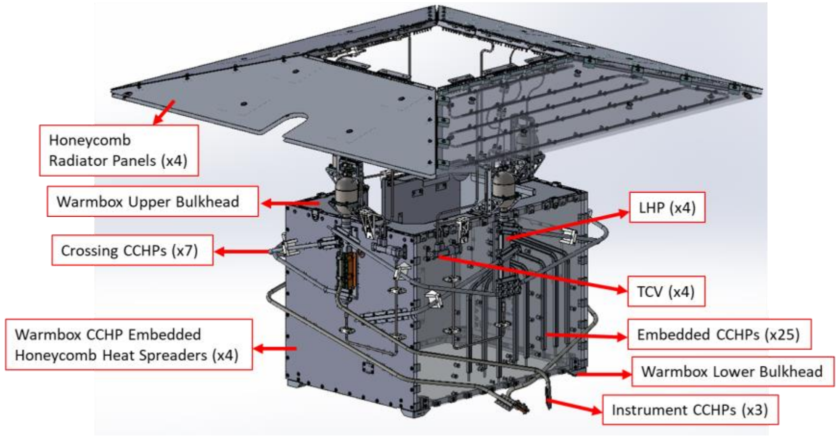
   – CCHPs used to take heat from the science instruments inside the warm box and transfer it efficiently to the LHPs, keeping the components below their max temperature limits
     - CCHPs and CCHP Panels have extensive flight heritage (micro-g more-so)
     - CCHP layouts had to be designed to be gravity aided – condenser above the evaporator - no matter the rover tilt (15 deg.)
       – Axial groove wick structure provides little capillary force for liquid return against lunar gravity

   – Honeycomb panels provide easy mounting surfaces and structural support



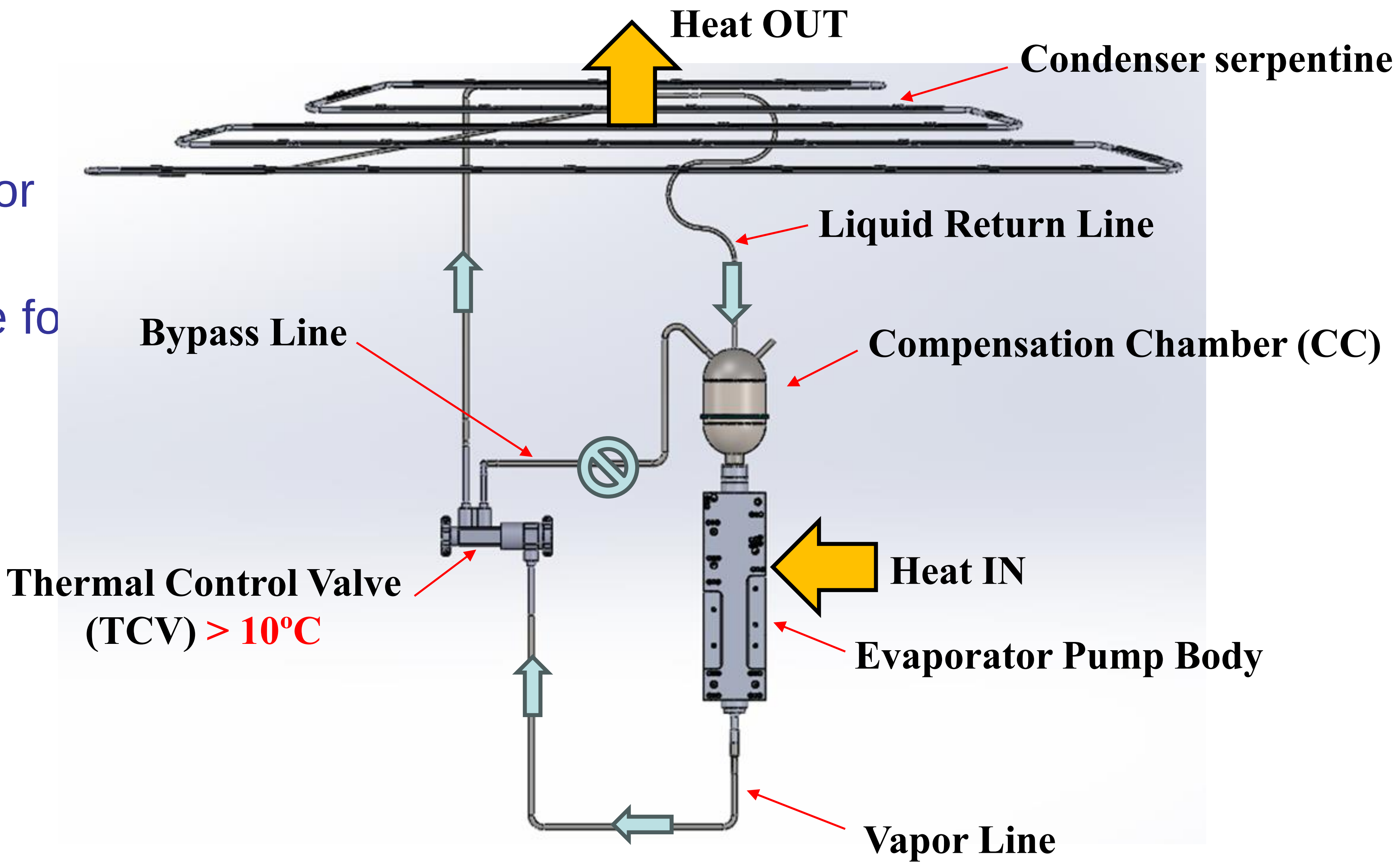
Main TMS Subsystems

4. Crossing CCHPs
   - Gravity aided CCHPs used for load sharing between the 4 LHPs around the warm box
   - Provide redundancy in the case of an LHP failure
   - CCHP layouts again designed to be gravity aided no matter the rover tilt (15 deg.)
5. Instrument CCHPs
   - Gravity aided CCHPs used for thermal control of the MSOLO and NIRVSS Instruments located outside of the central warm box towards the base of the Rover
   - Interface directly (or near directly) to instruments themselves and route to 3 of the 4 LHP evaporator bodies for heat rejection



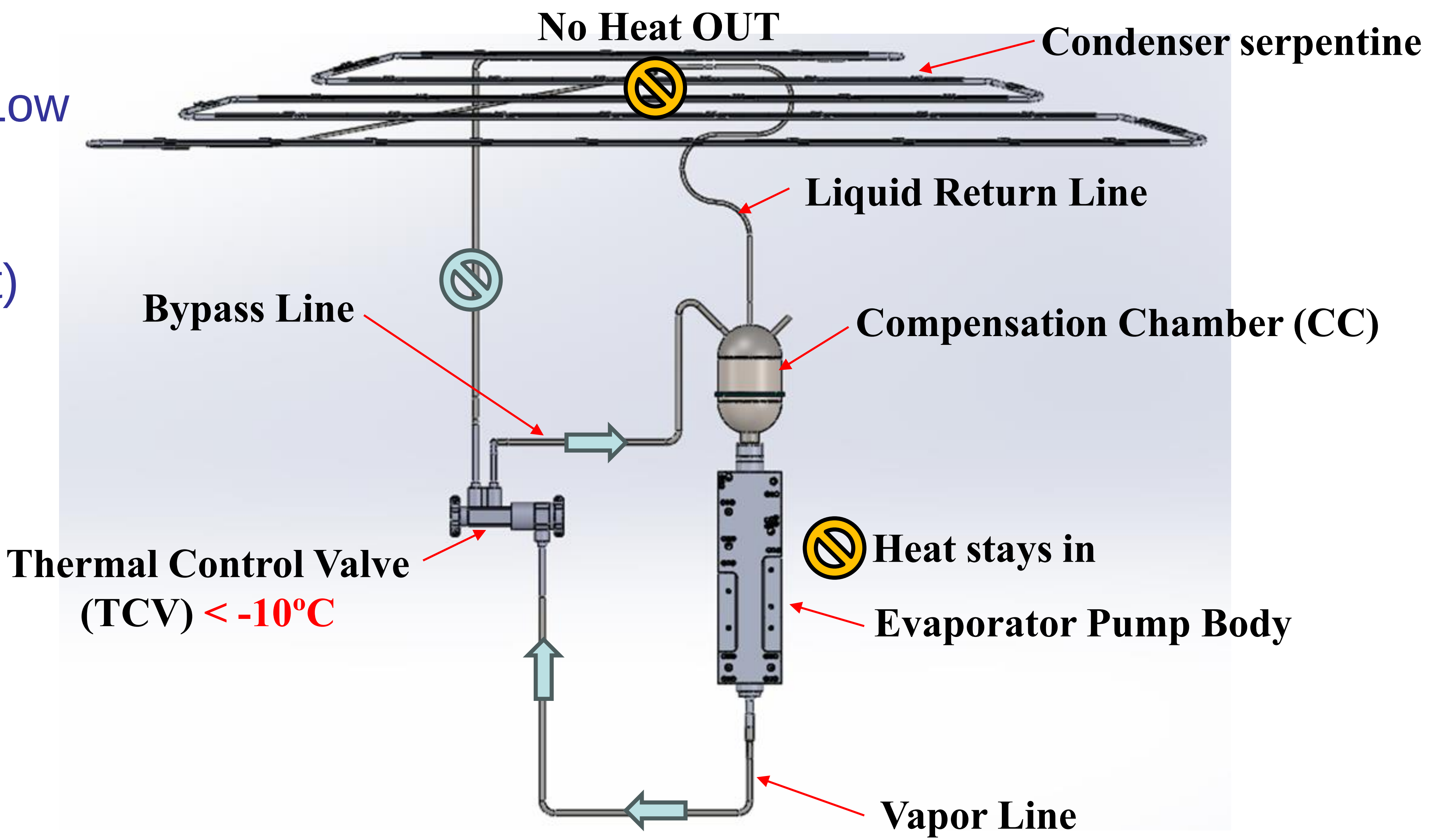
Lhp with tcv - concepts

- Normal Flow operation shown for above 10ºC
- High Conductance fo Daytime Science Operations



Lhp with tcv - concepts

- Bypass open for Low Conductance operation below -10ºC (Lunar Night)



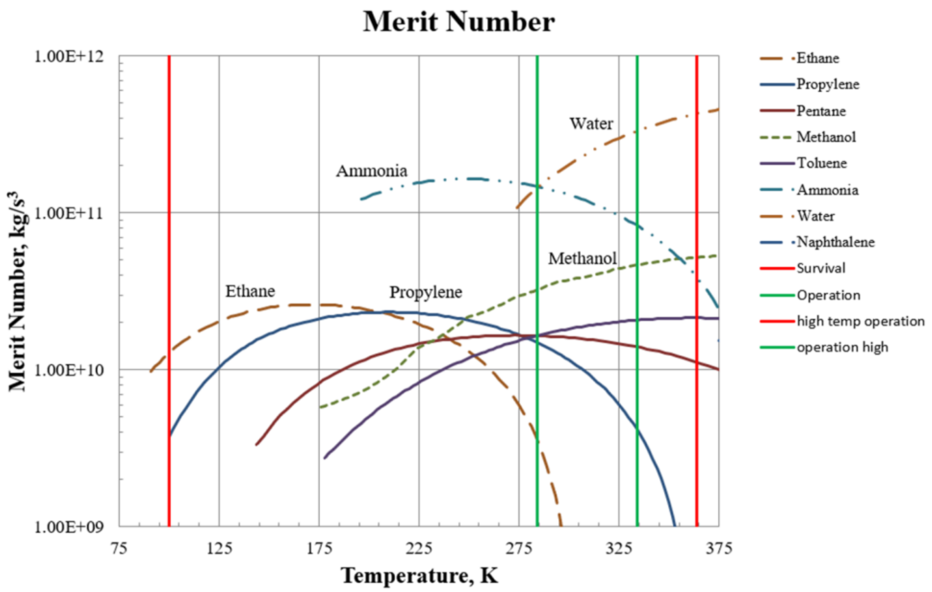
Design process overview

1. Radiator Design/Sizing
   - Known power input based science instruments and optical properties based on paint chosen → Z93C55
   - Hand Calculations and Finite Element Analysis (FEA) later

Design process overview

2. LHP Design/Sizing

- Choice of working fluid (operating temperature range, merit number based on fluid properties and power transport needs, etc.) → Propylene
- Radiator size can be used to size the condenser length/serpentine
- Rover structure can be used to define the transport line lengths
- Evaporator Body/Wick sized based on power transport needs and mating area
- Size compensation chamber based on fluid volume needed for the condenser length, transport line lengths, and wick size (cold – near full ~85% vs. hot – near empty ~15%)
- Estimate conductance based on evaporator body geometry, wick design, etc.
- Hand Calculations



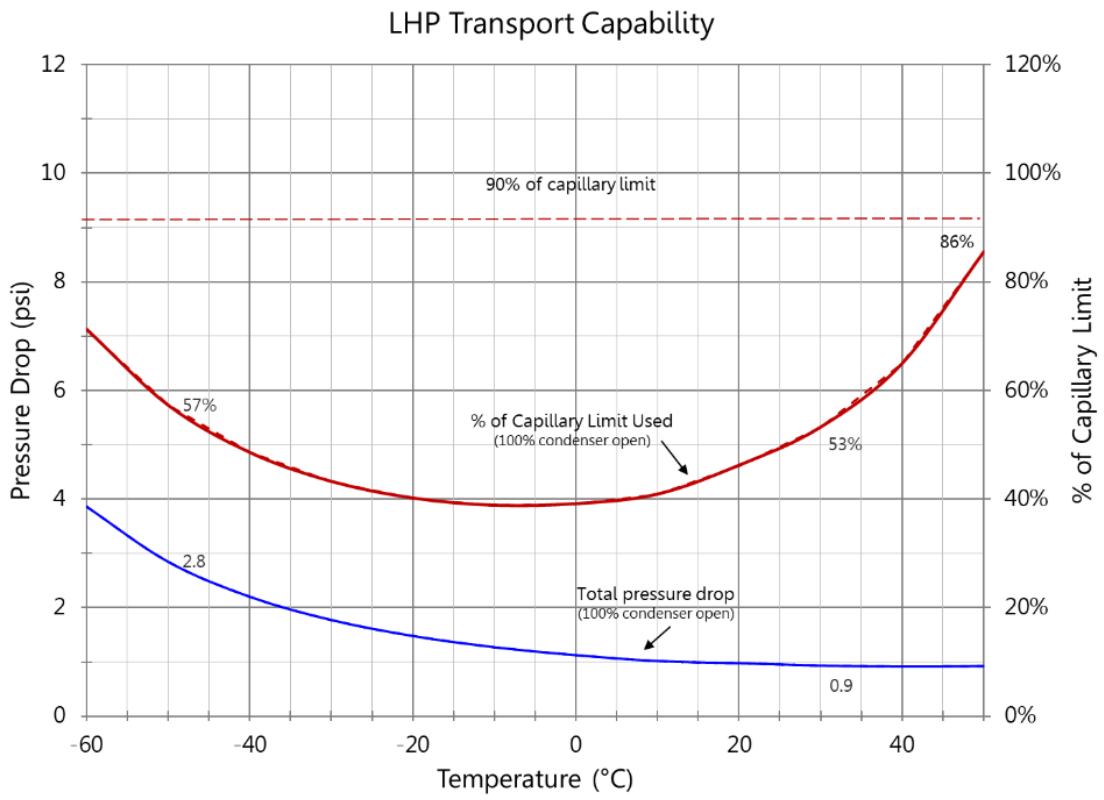
Design process overview

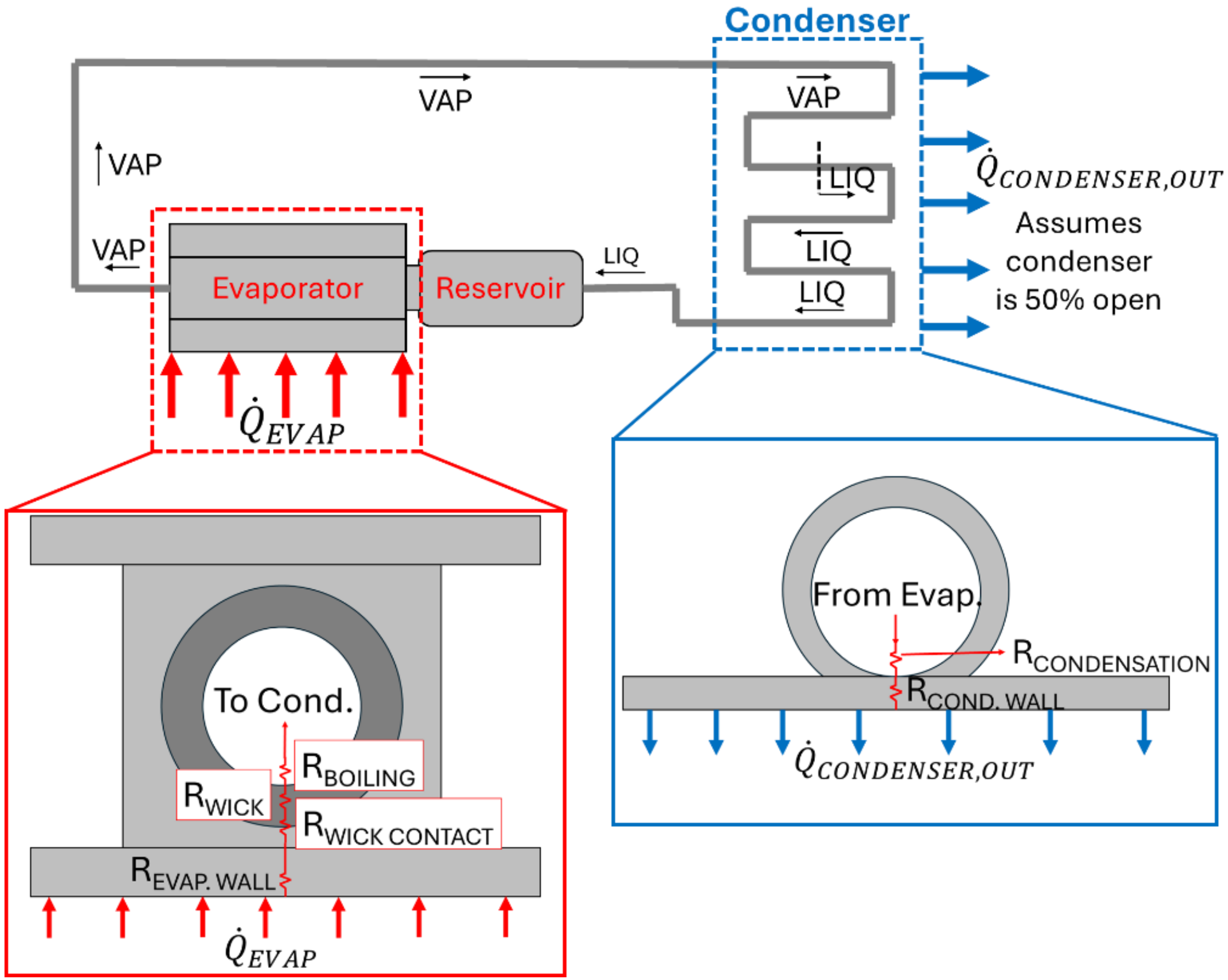
3. TCV Selection
   – TCV switching point (setpoint) informed by component temperature limits and predicted LHP conductance to radiator → -10/10 C
4. Heat Spreader CCHP Layouts
   – General size of heat spreader panels driven by component sizes and locations in the warm box (NASA controlled)
   – Using LHP footprint and component footprints and locations, design heat pipe layout to move heat from the components to the LHP footprint
   – Finite Element Analysis and Hand Calculations

Design process overview

5. Connecting CCHP Layout/Design
   - Done roughly in parallel with the Heat Spreader design
   - Once the LHP sizing was completed, the connecting CCHPs could be designed
   - Select extrusion based on power transport needs and dT requirements
   - Hand Calculations
   - CAD layout based on warm box size and LHP size (15 degree requirement)
   - Hand Calculations
6. Instrument CCHPs Layout/Design
   - Done later in the programs design cycle, but could have been done in parallel with heat spreader design and connecting CCHP
   - CAD layout based on instrument (MSOLO/NIRVSS) locations relative to the warm box (15 degree requirement) → NASA driven w/ ACT support
   - Hand Calculations

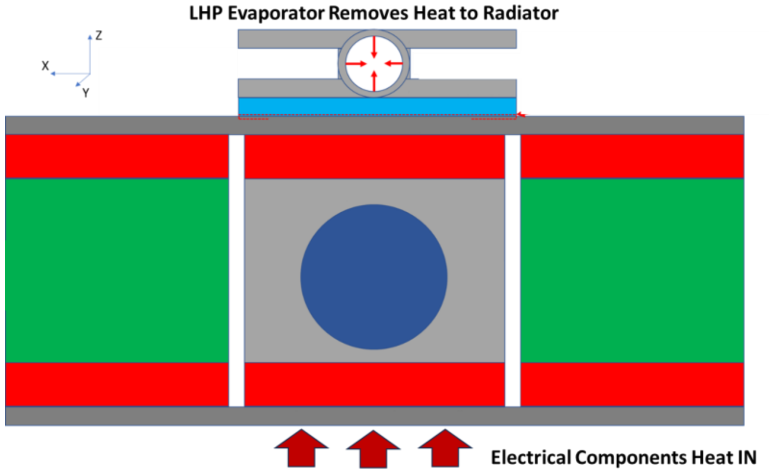
Design Process - LHP



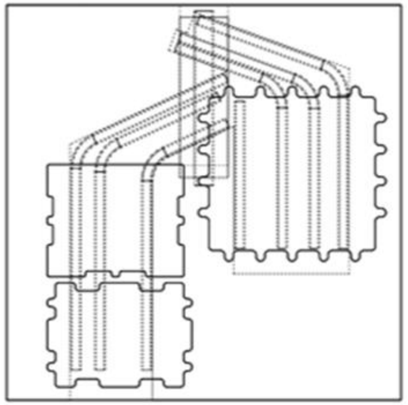


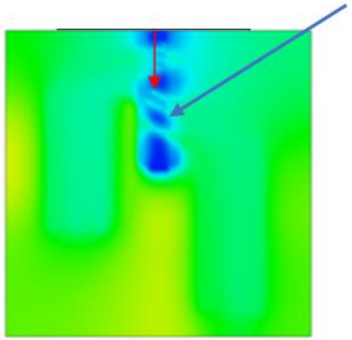
Design process - Heat Spreaders

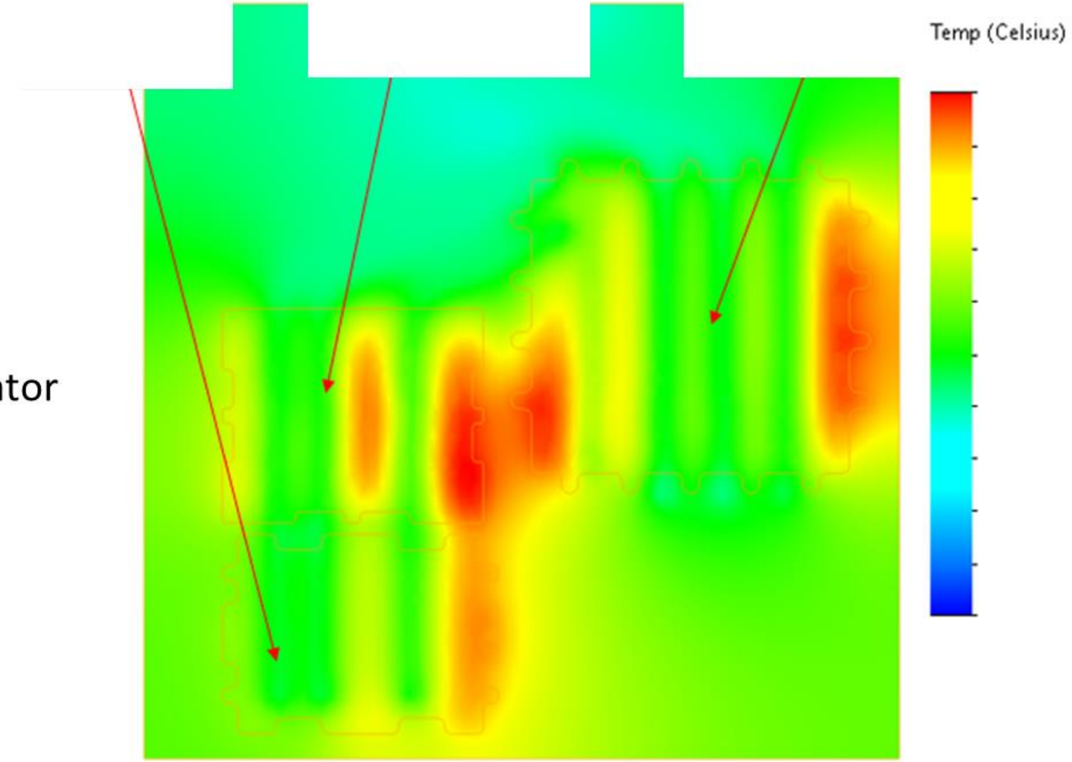
Boundary Condition: High (two phase) heat transfer coefficient on LHP Bore



Color	Material
(light gray)	6000 Series Aluminum
(dark gray)	7000 Series Aluminum
(light blue)	Graphite Sheet
(red)	Film Adhesive
(green)	Aluminum Core (anisotropic properties)
(dark blue)	CCHP Vapor Space - High conductivity material

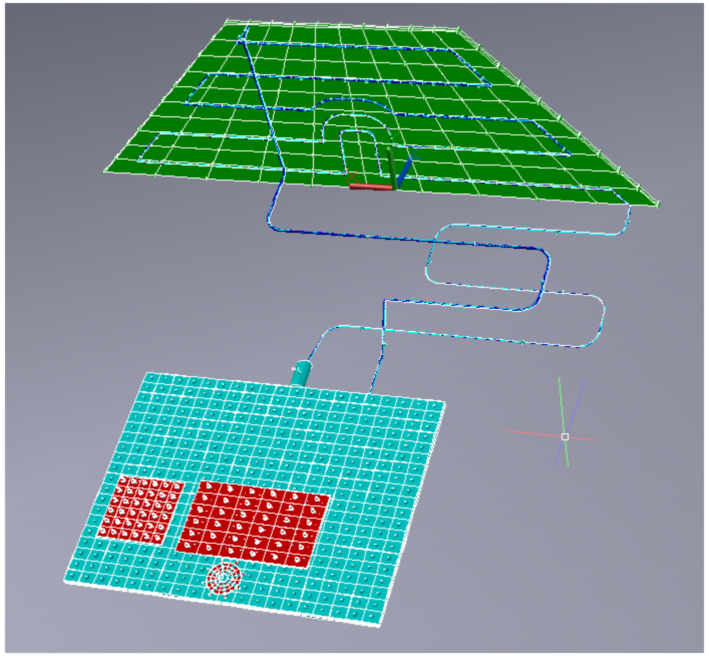
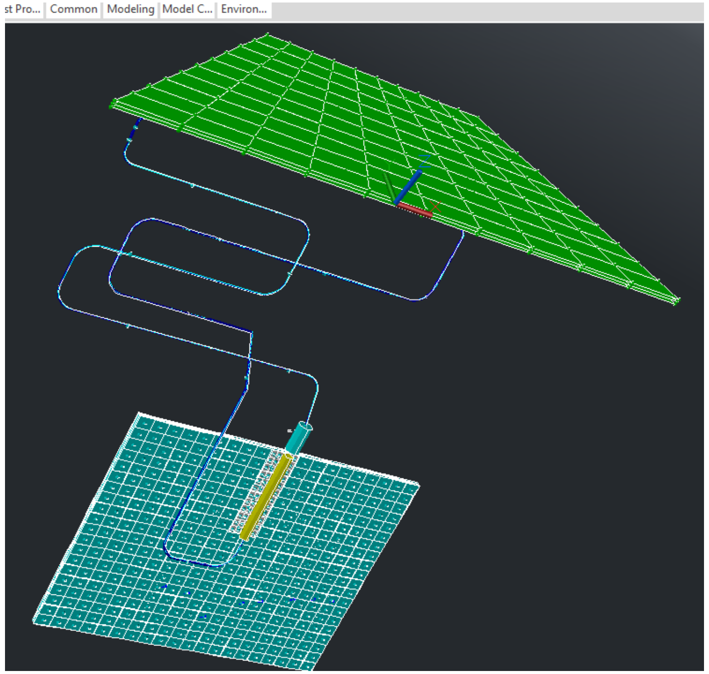


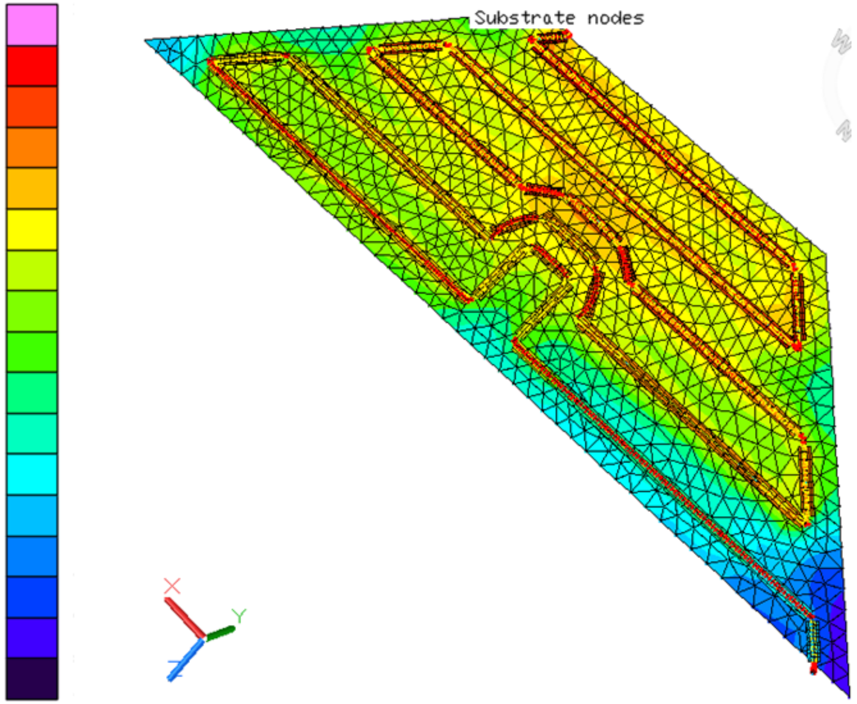




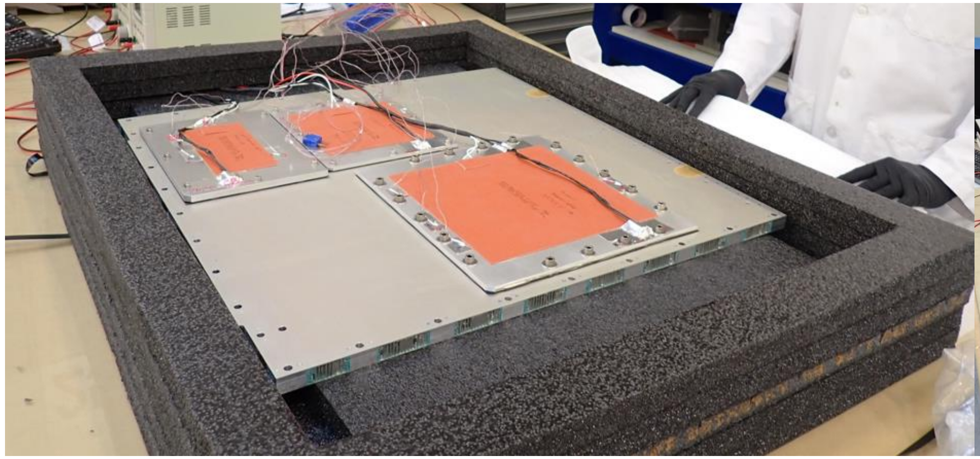
Design Process – quarter system

- Port Heat Spreader, LHP, and Radiator analyzed in FEA including radiation to confirm design performance would meet requirements

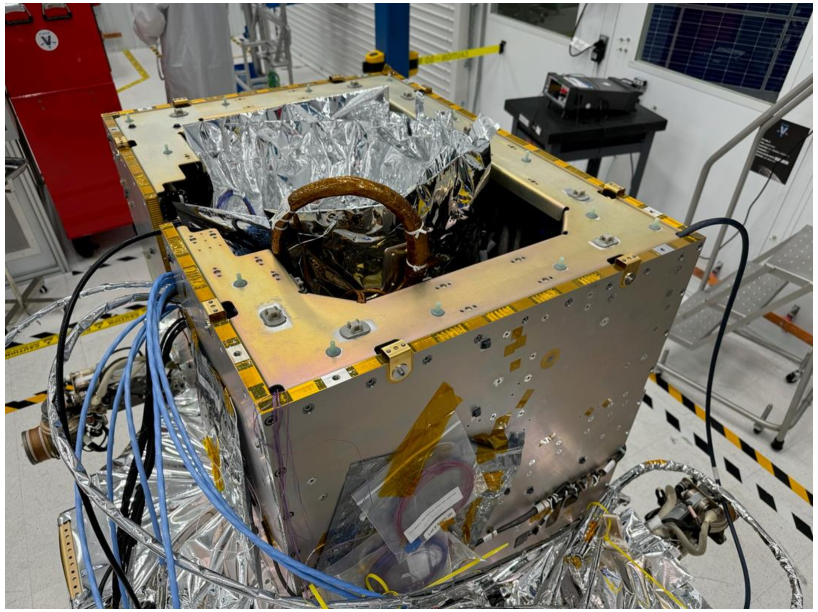



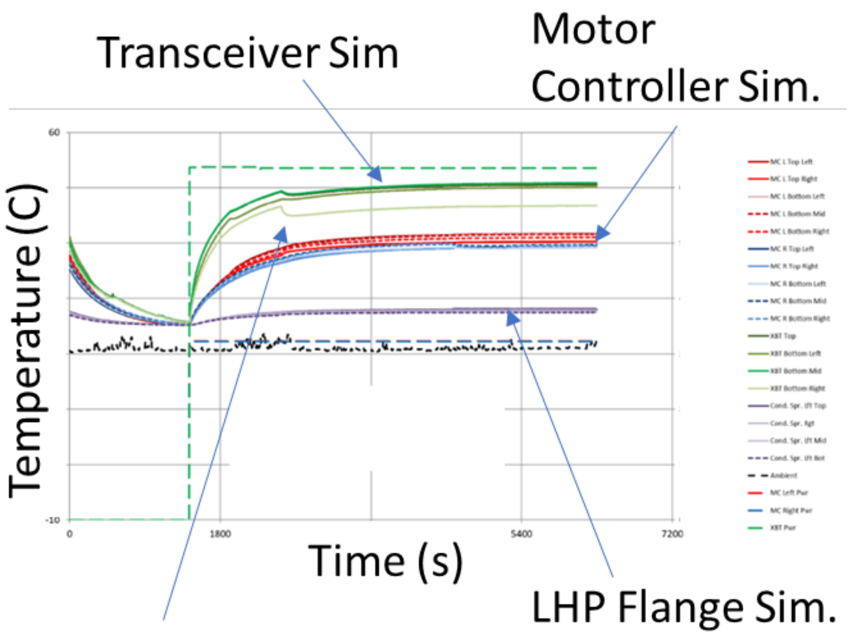


Build & Testing – Heat Spreaders



Heat Spreaders built at ACLA with ACT supplied CCHPs. Heat spreaders tested at both ACLA and ACT.



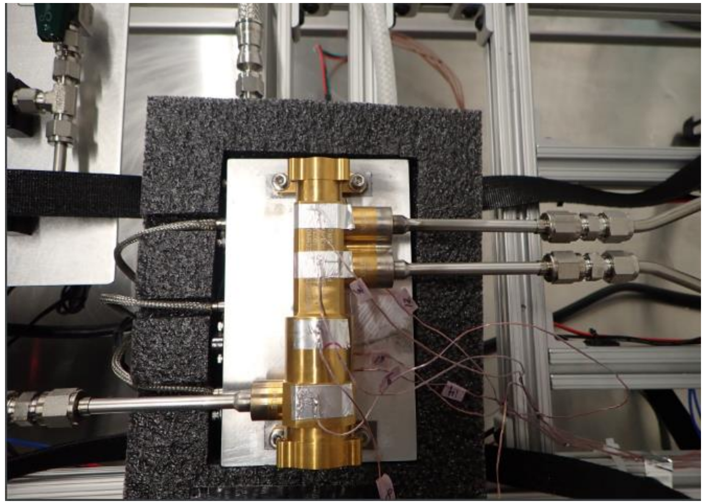


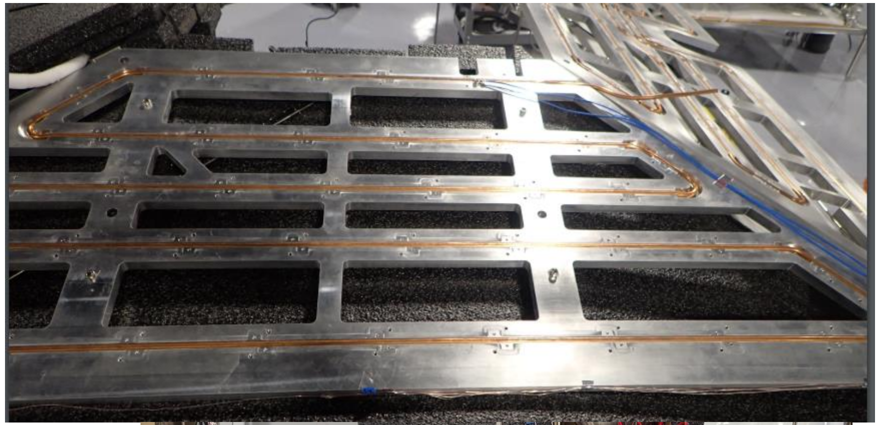
Startup transients seen due to gravity causing CCHP liquid pooling

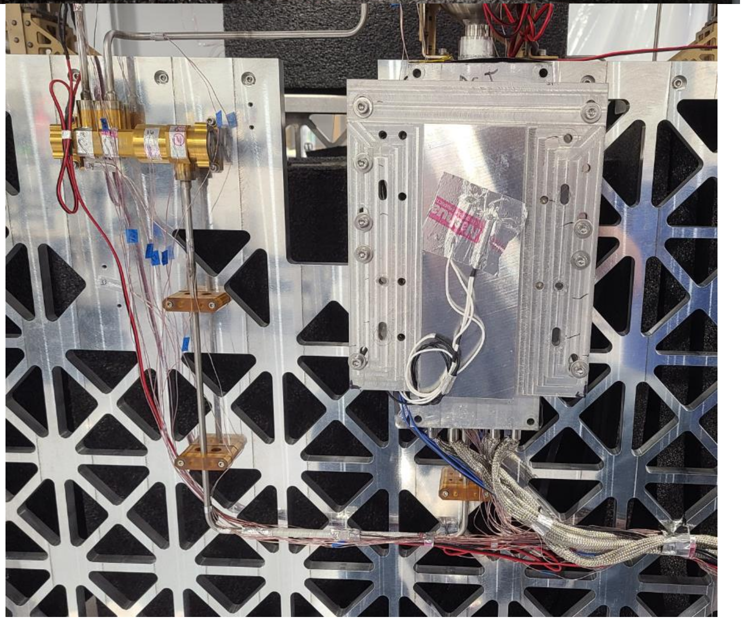
Heat Spreaders (and Bulkheads) integrated onto the Rover

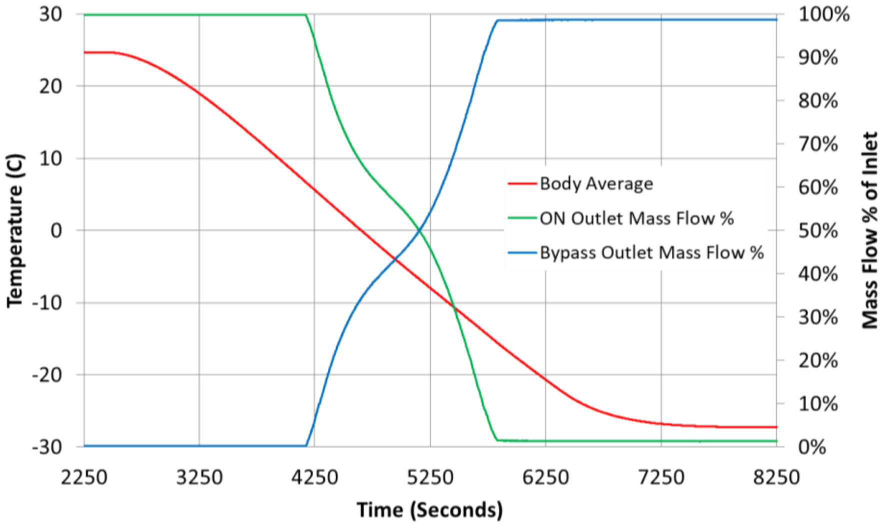
Build & Testing – LHP w/ TCV

TCVs built at PDT/Ametek and tested at both PDT and ACT

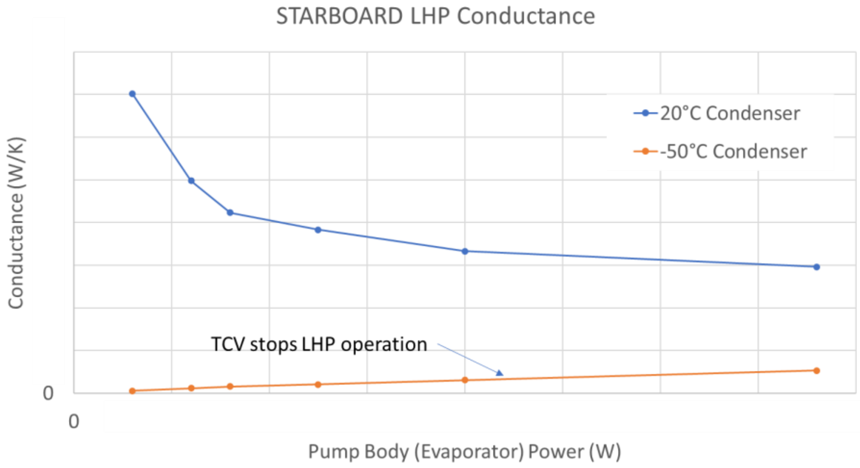


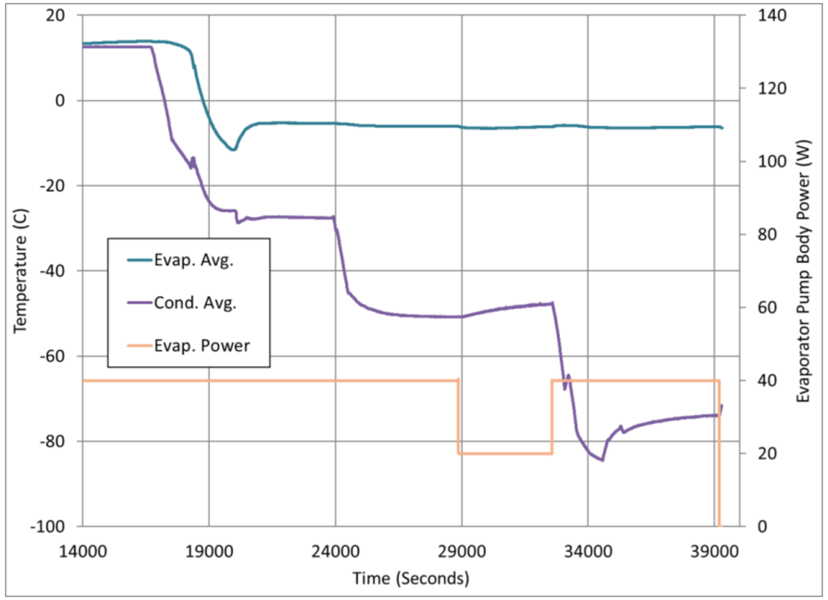




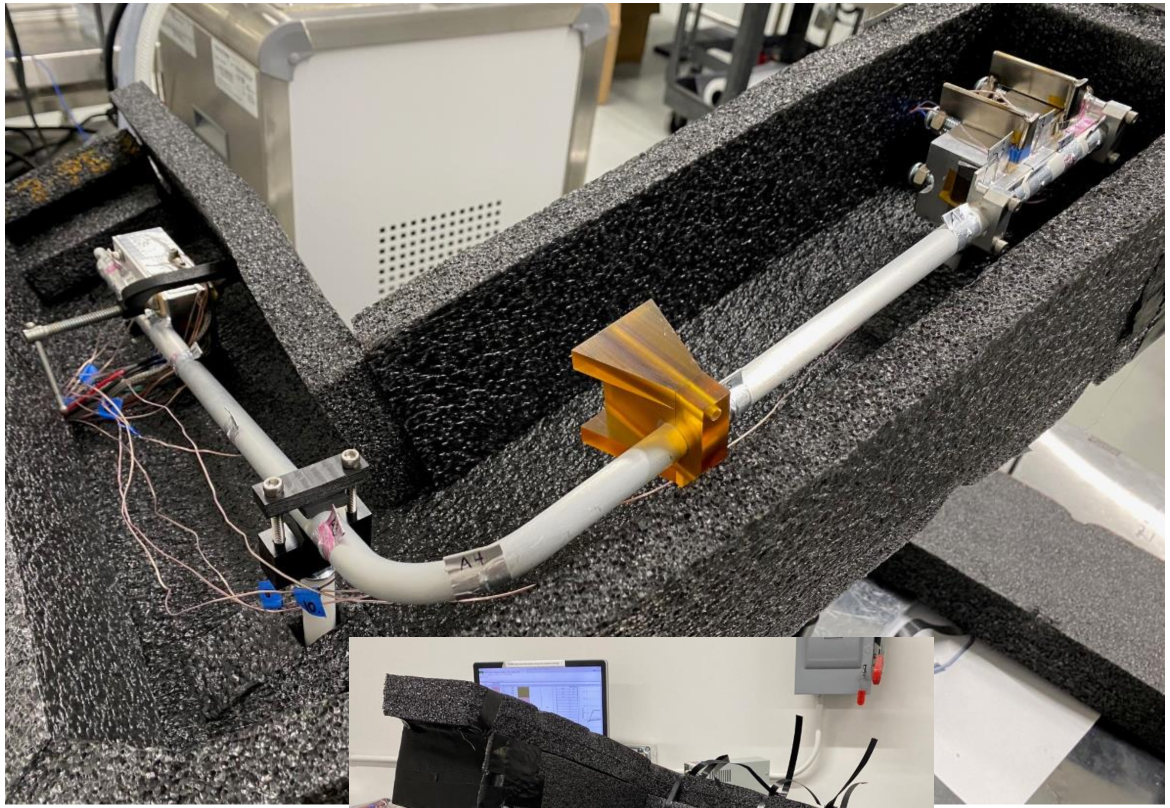


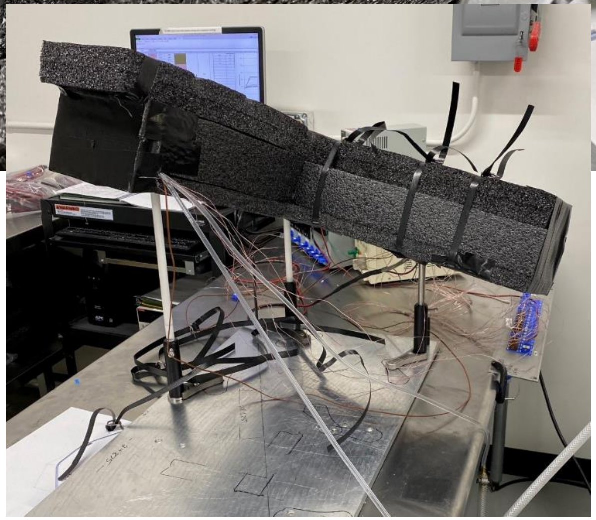
LHPs built and tested at ACT





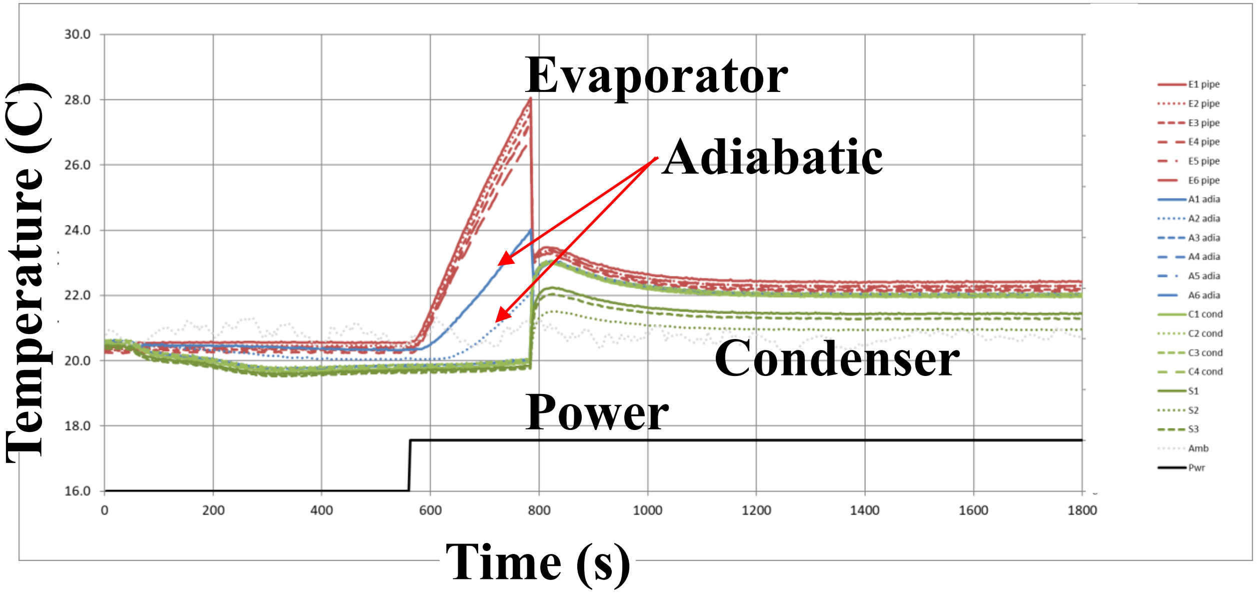
Build & Testing – Crossing CCHPs



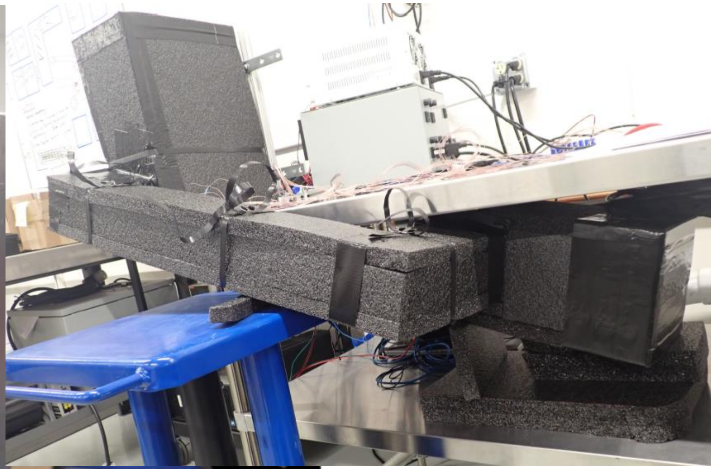


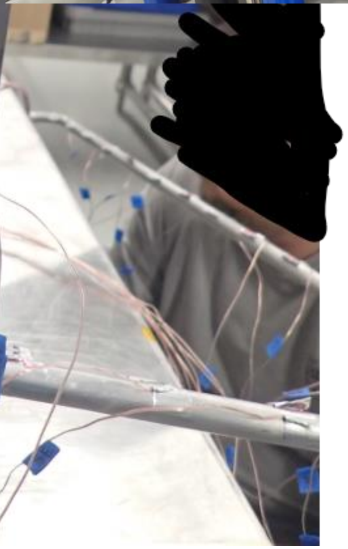
Crossing CCHPs built and tested at ACT

Startup temperature spike due to liquid pooling in evaporator

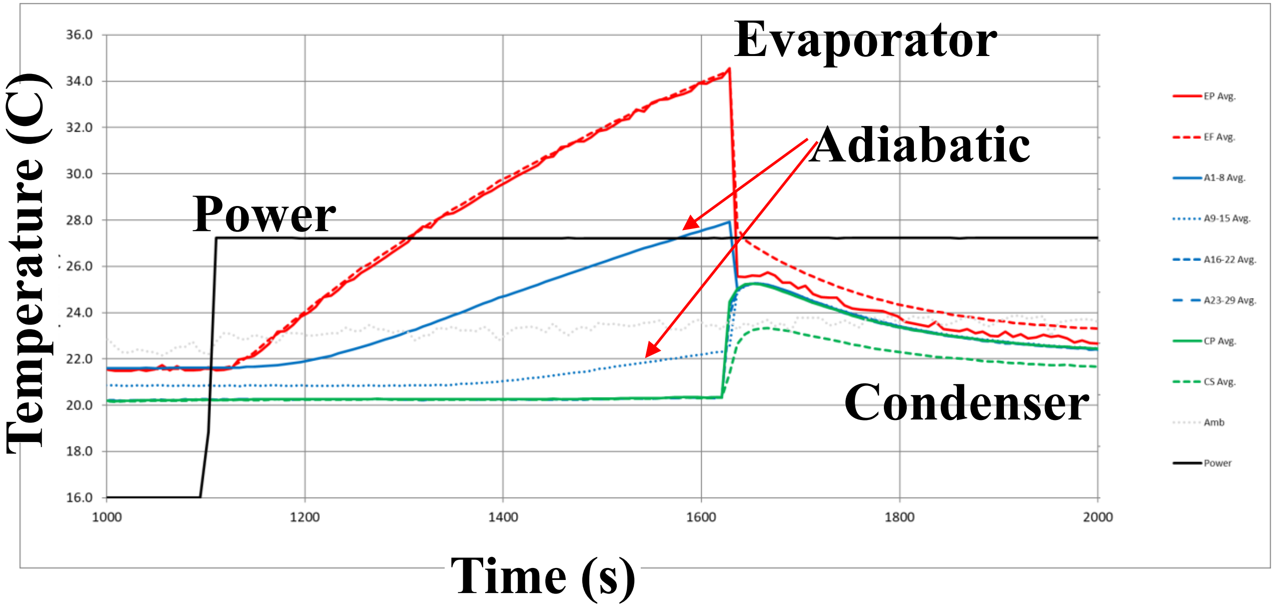


Build & Testing – Instr. CCHPs





Instrument CCHPs built and tested at ACT

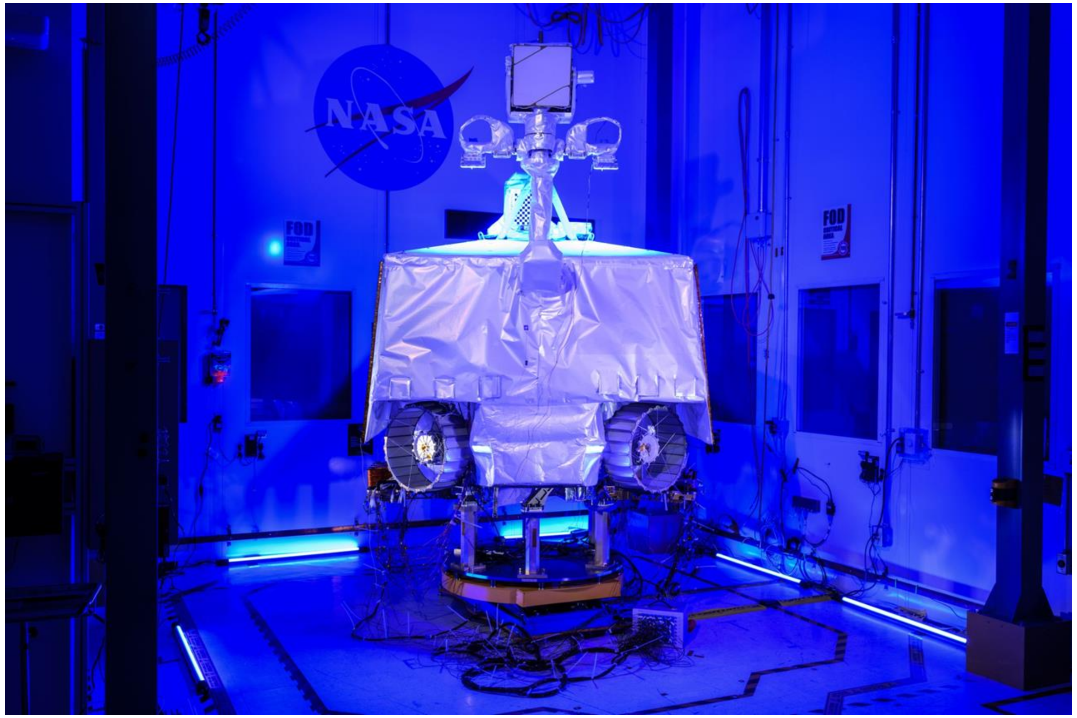


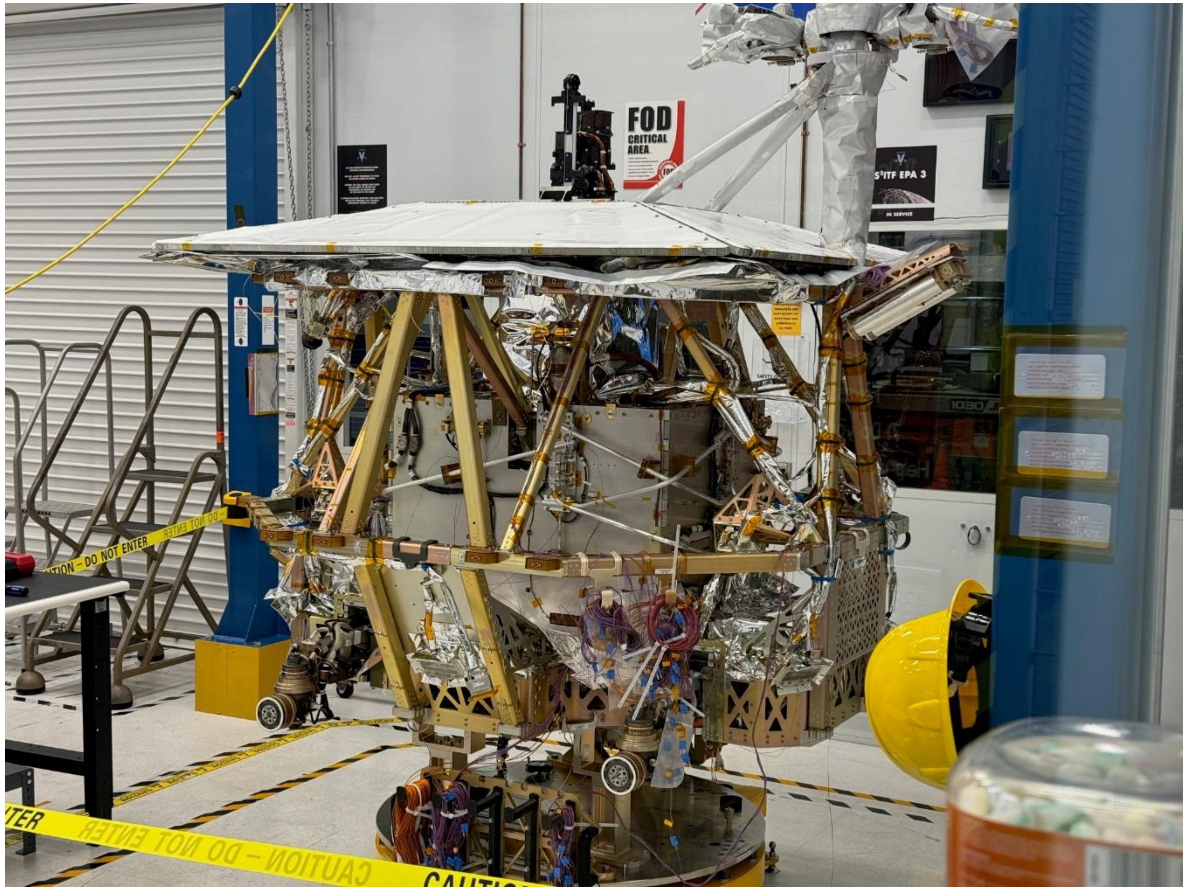
Summary and Current Status

- ACT worked with NASA to develop a TMS for the Viper Rover that could withstand the challenging thermal environments including Lunar Night Survival
- The main subsystem of the TMS was 4 LHPs with integrated TCVs that provided high conductance to the radiators during the Lunar Day to keep science instruments under max temperature limits, and very low conductance to the radiators during the Lunar Night to keep components warm
- Other subsystems included embedded CCHP honeycomb heat spreaders and gravity aided CCHPs for load sharing between LHPs, as well as instruments located outside of the warm box

Summary and Current Status

- Current Status: TMS fully integrated and through Vibration and Acoustic Testing
- Rover project cancelled on July 17th, 2024





References

[1] https://ametektms.live.ametekweb.com/pressreleases/productnews/pdt/ametek-pdt-partners-with-nasa