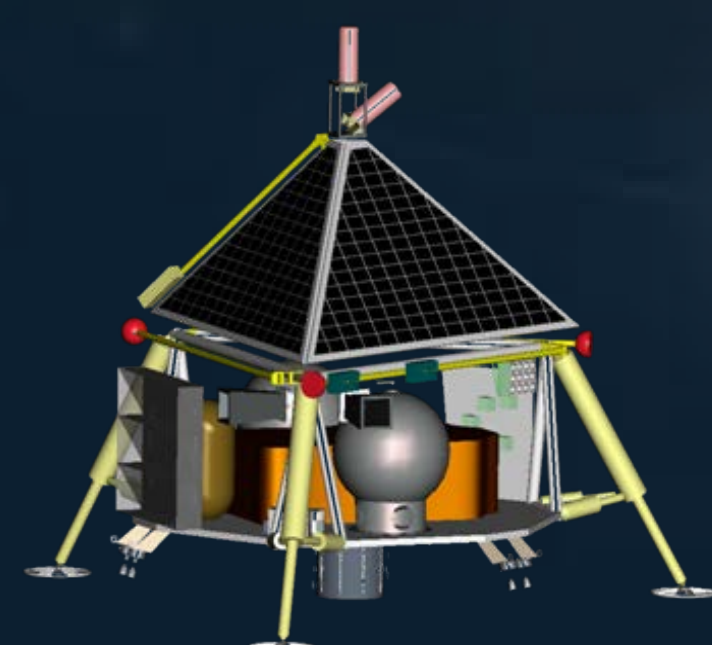


Advanced Thermal Control & Systems Design Enable Long Duration, Continuous Lunar Surface Operation of Robotic Science Landers and Payloads

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Reference Mission/Challenge: Support monitoring of geophysical conditions at multiple sites on lunar surface continuously thru the lunar day/night cycle for extended duration (6 years). (Reference: International Lunar Network)

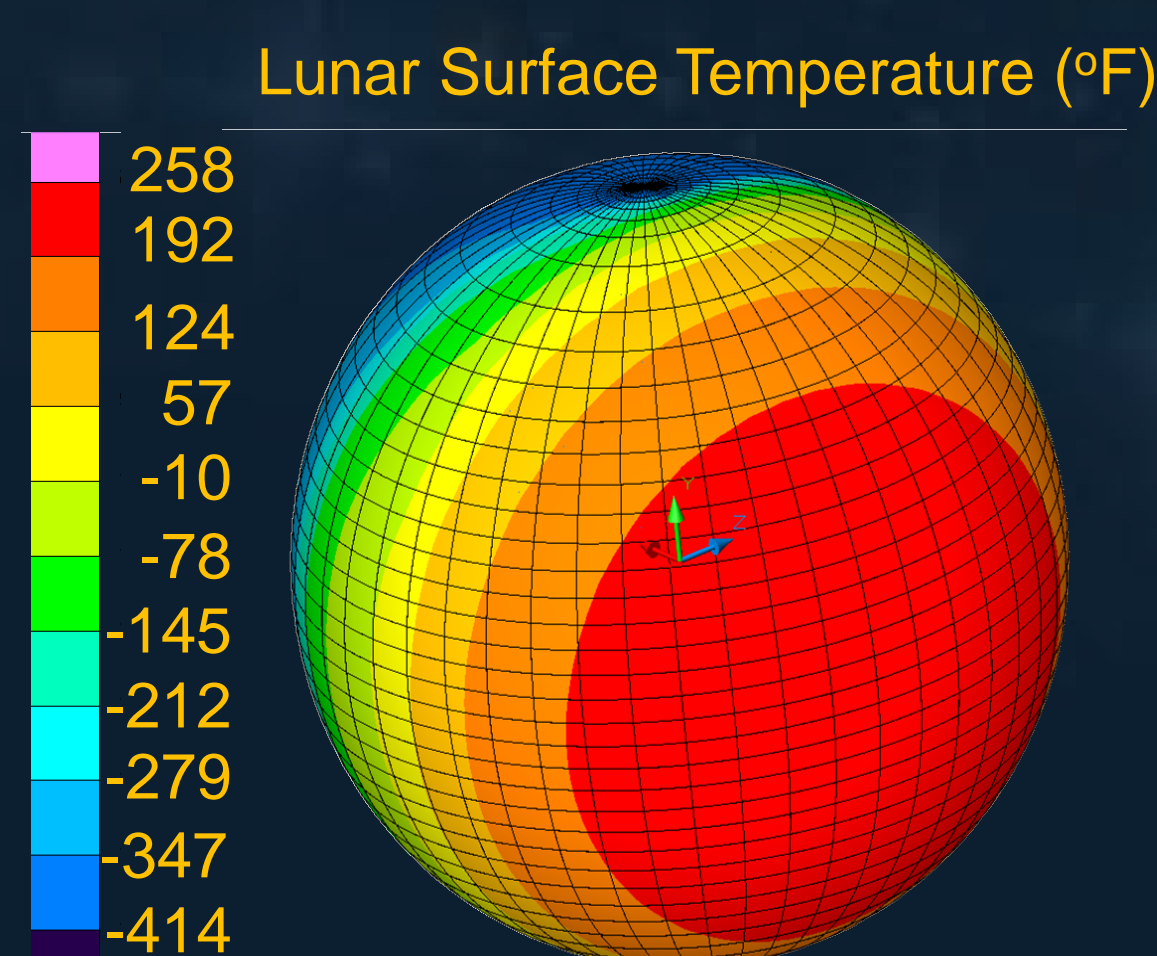


Instruments:

- Siesmometer for measurement of tectonic movement
- Electromagnetic booms for EM field measurements
- Mole for Subsurface temperature & heat flow measurements

Thermal Environmental Challenges:

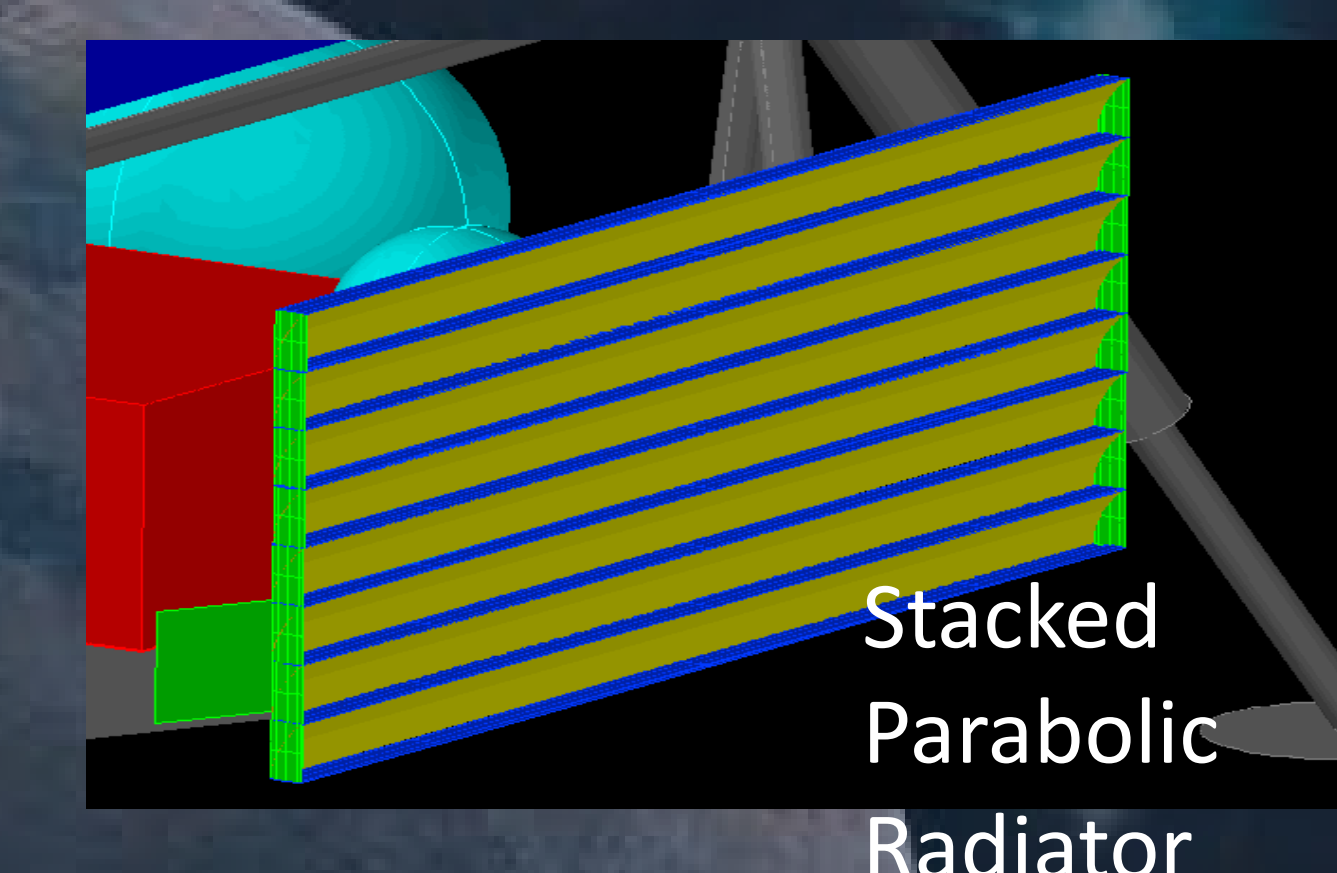
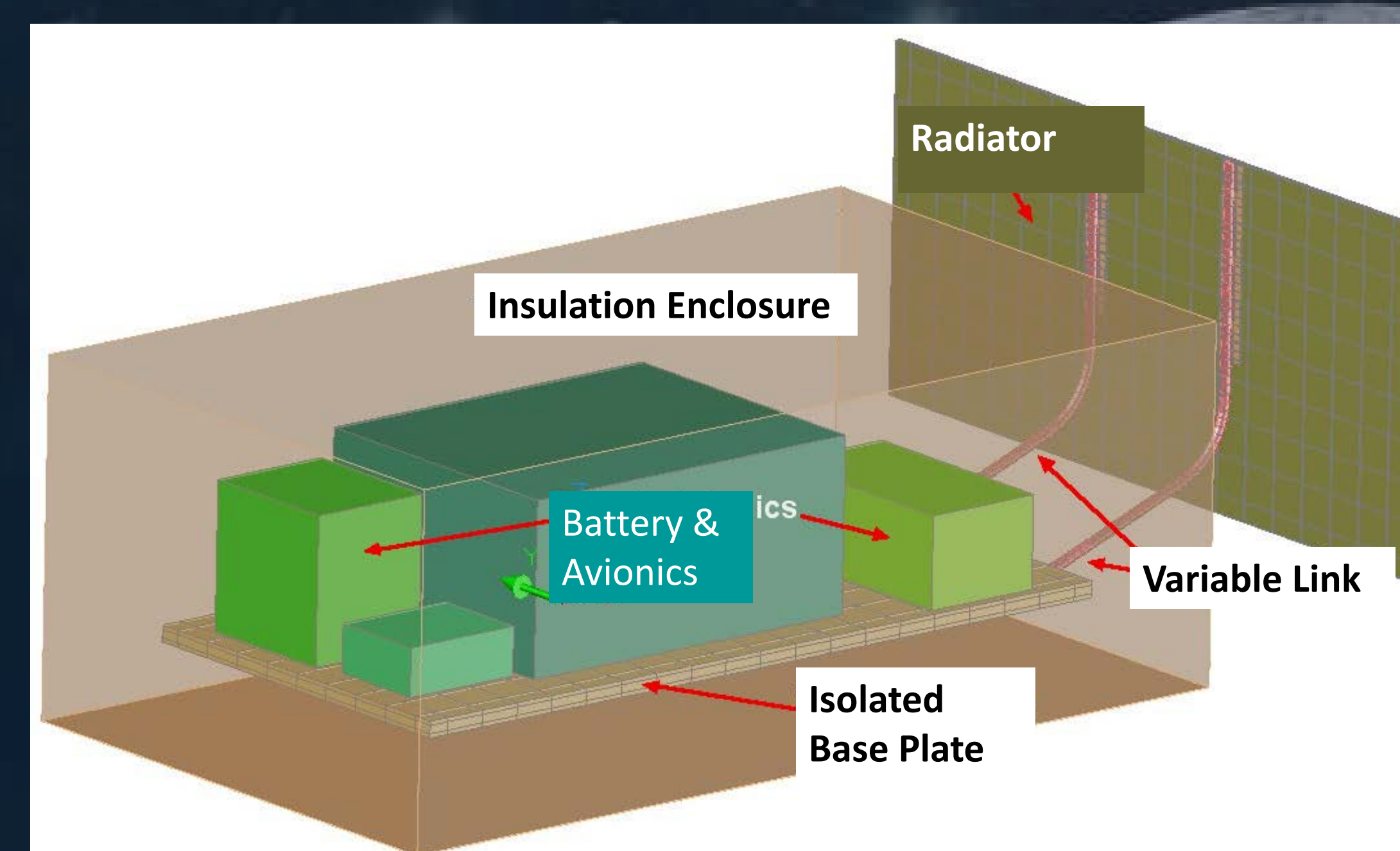
- Cold nighttime temperatures (~100K); even colder in permanently shadowed regions
- High daytime temperatures (~400K) at local noon for some locations
- Extreme conditions persist for weeks
- Dust can degrade optical properties.
- Vacuum & low conductivity regolith limit heat rejection options to radiation to space



Power/Thermal Assumptions and Design Approach:

Key assumptions: Power sources limited to solar PV and batteries. Batteries are sized to provide power thru lunar night & other mission needs.

- Group together & completely Insulate/isolate sensitive electronics & batteries used on lunar surface to share heat & maximize heat conservation
- Connect insulated electronics to radiator via Variable heat transport link.
- Variable heat transport link maximizes heat transport to radiator during lunar day but drastically limits heat transfer during lunar night.
- Radiator customized via configuration, optical properties, orientation, size, & location to maximize heat rejection to space



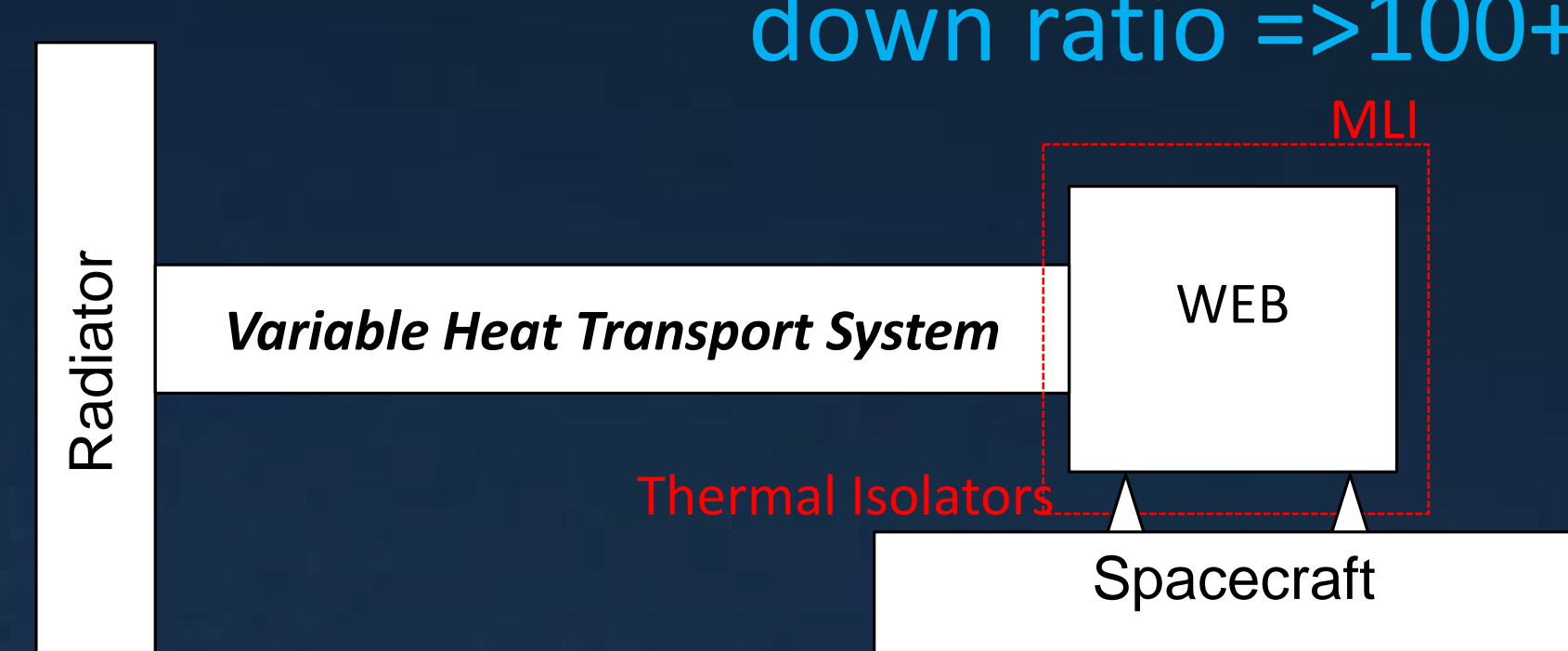
Variable Heat Transport Link Technology Development

Variable Link Technology Trades

Score = Control Power * Lifetime * Complexity * Tilt

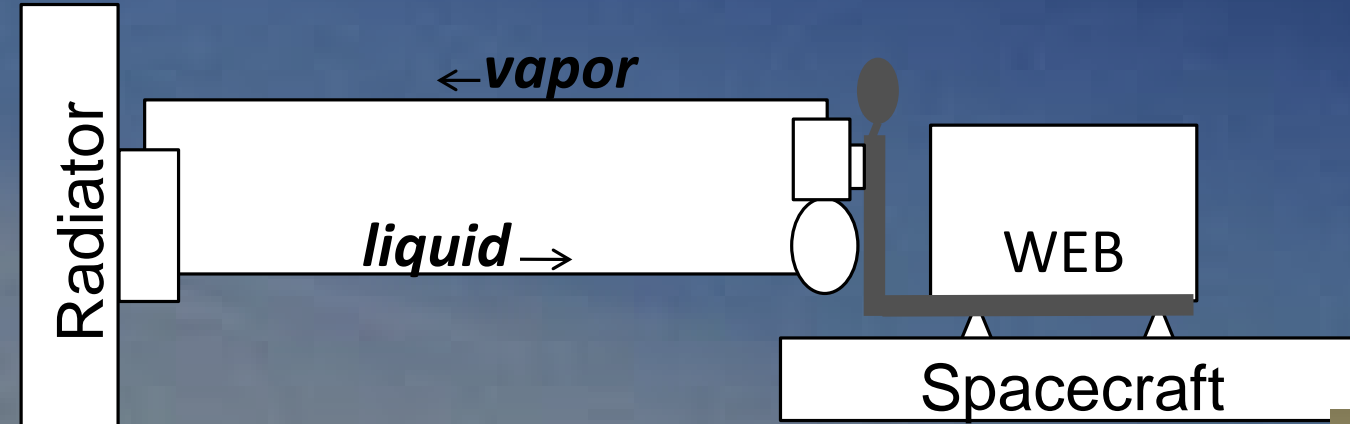
System	Control Power	Lifetime	Complexity	Tilt Tolerance	Score	Conclusion*
1. VCHP	4.0	4.0	4.0	2.0	128	2
2. CPL	1.0	4.0	2.5	4.0	40	Eliminate
3. LHP	1.0	4.0	3.0	4.0	48	5
4. HLHP	1.0	4.0	2.0	4.0	32	Eliminate
11. HLHP/Valve	1.0	1.0	1.0	4.0	4	Eliminate
12. LHP/BV	4.0	3.0	2.5	4.0	120	3
13. LHP/HX+SC	3.5	4.0	2.0	4.0	112	4
14. VCHP/VCHP	4.0	4.0	3.5	2.0	112	4
15. CPL/VCHP	1.0	4.0	2.0	4.0	32	Eliminate
16. LHP/VCHP	3.5	4.0	2.5	4.0	140	1
17. HLHP/VCHP	1.0	4.0	1.5	4.0	24	Eliminate
25. LHP/MEC	1.0	4.0	1.0	4.0	16	Eliminate
26. HLHP/MEC	1.0	4.0	1.0	4.0	16	Eliminate

Each option operated passively & achieved turn down ratio =>100+

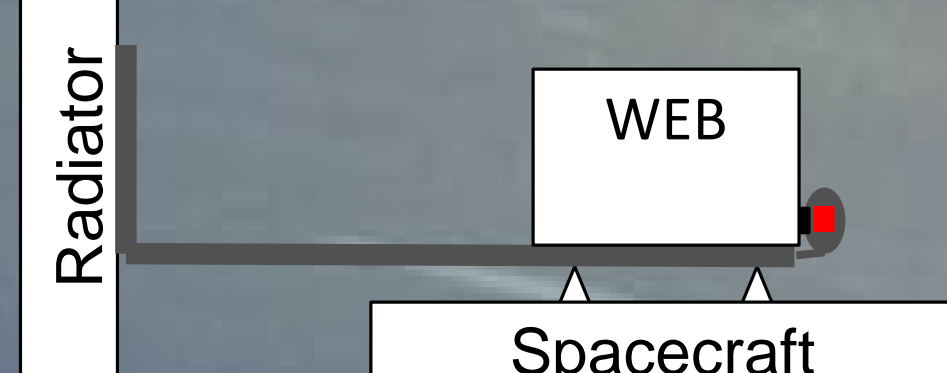


Development & Testing of Variable Links

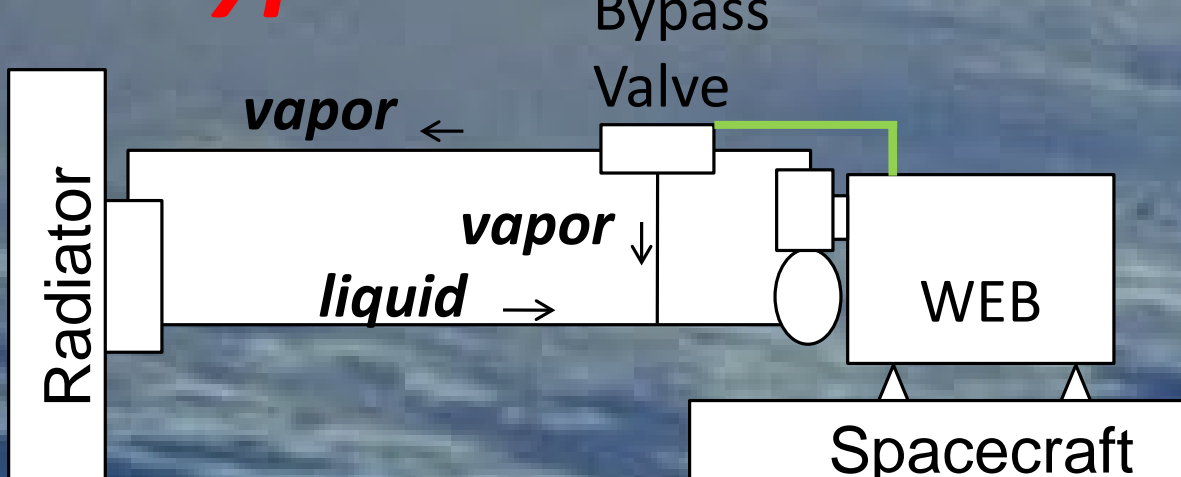
LHP/VCHP



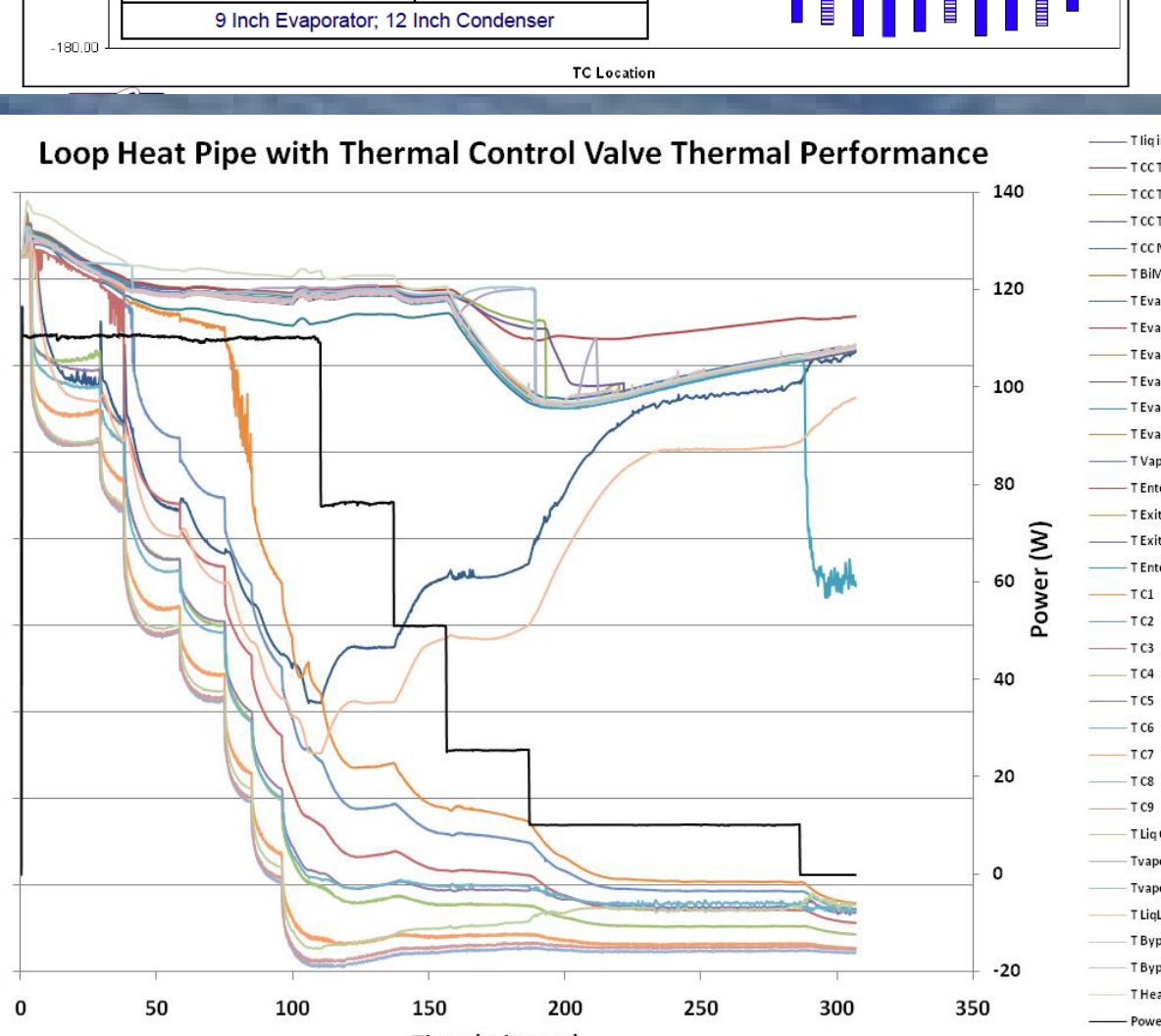
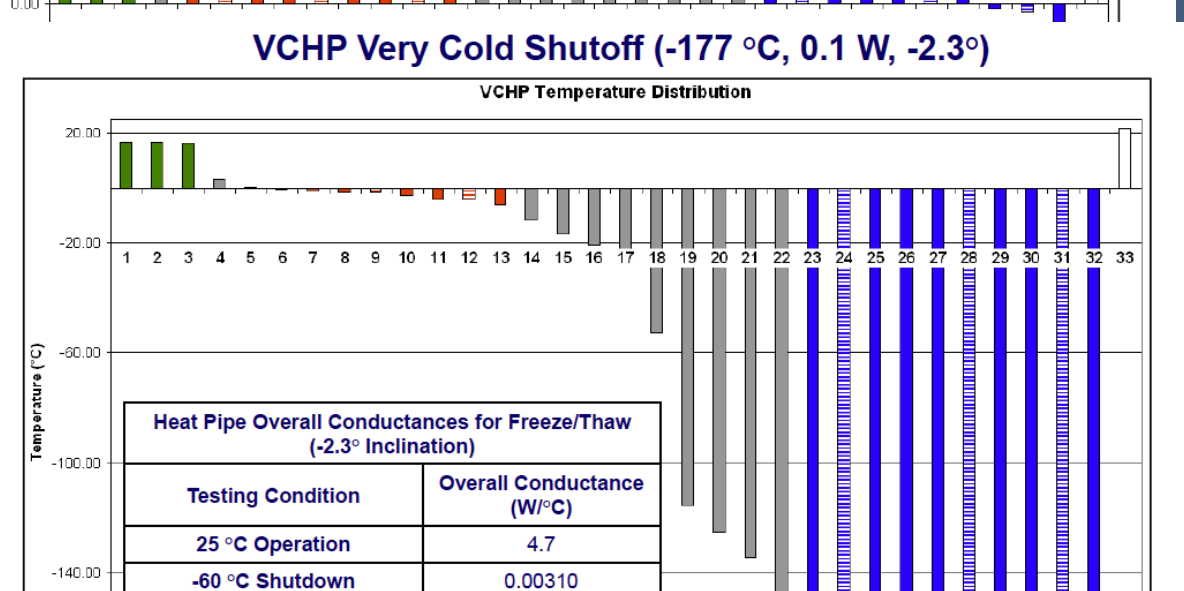
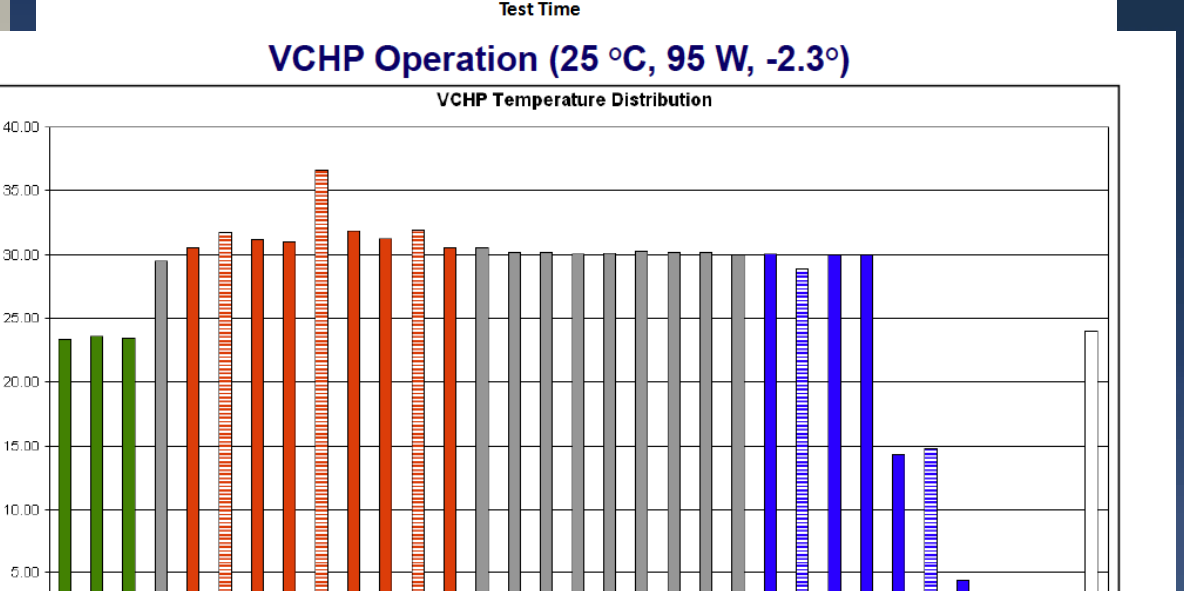
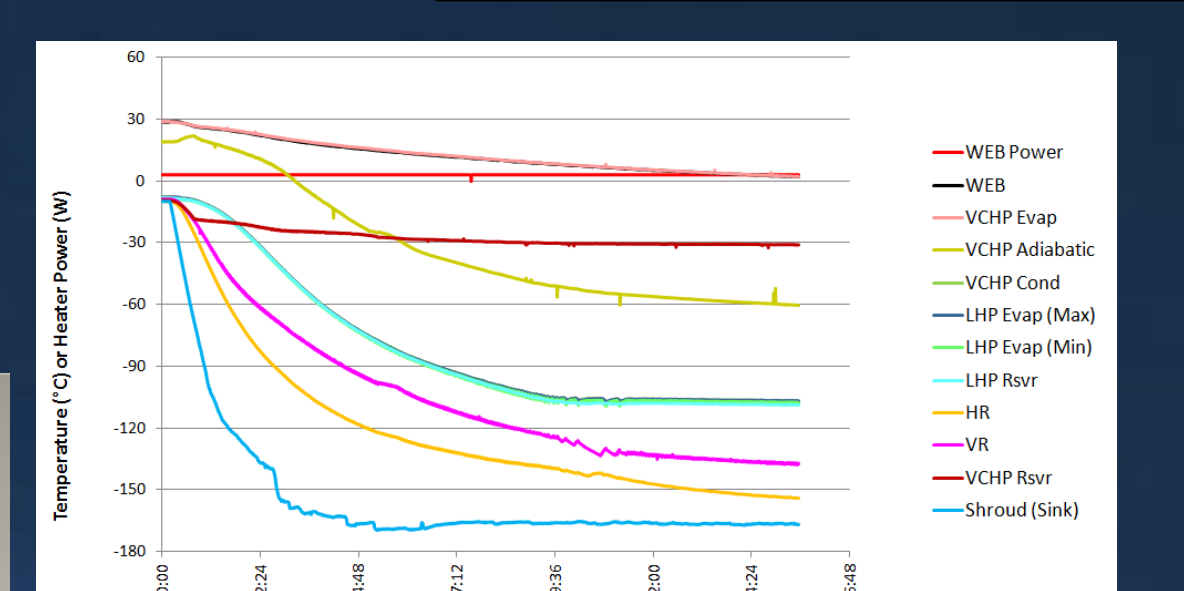
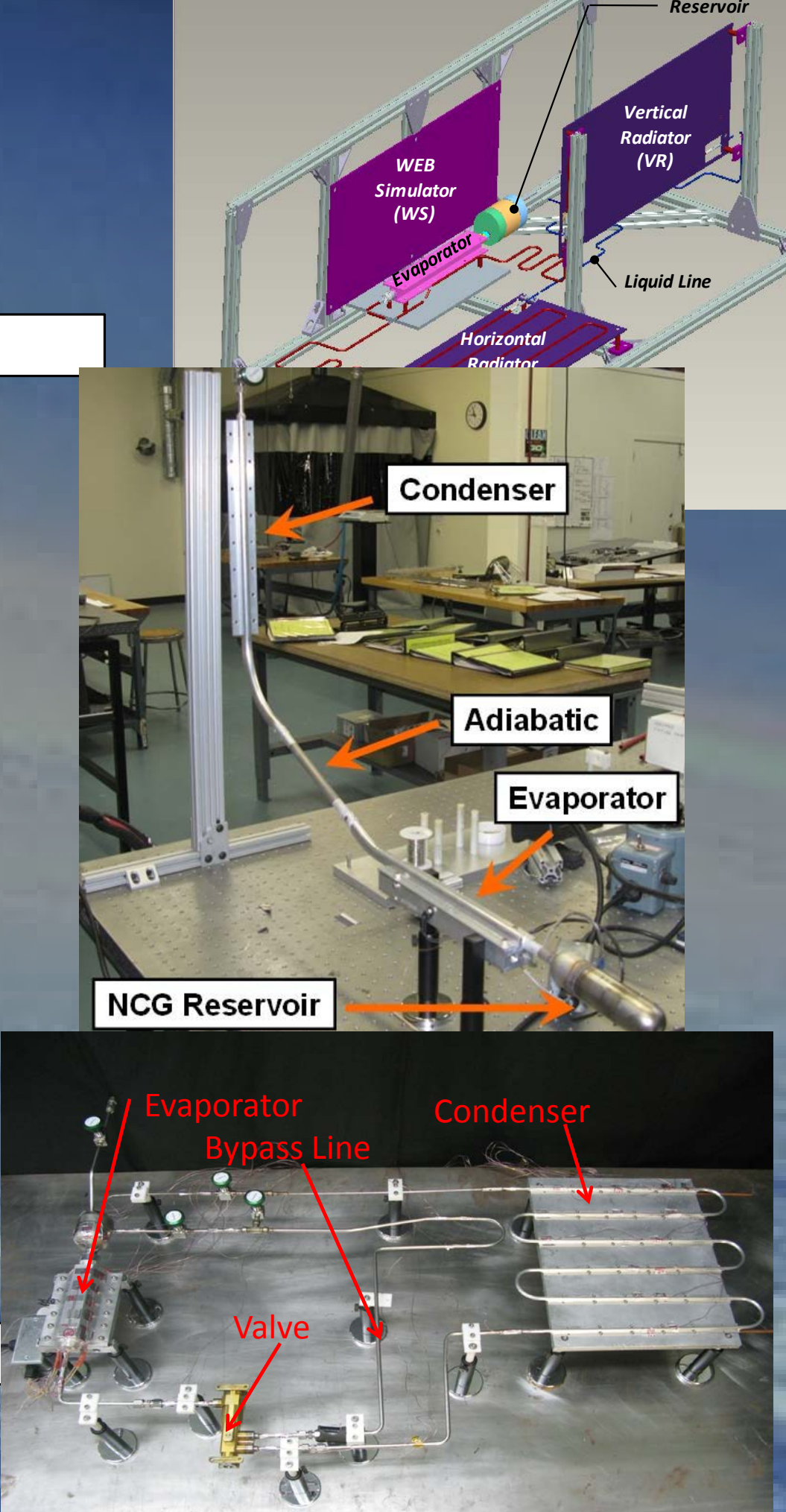
Warm Reservoir, Hybrid wick VCHP



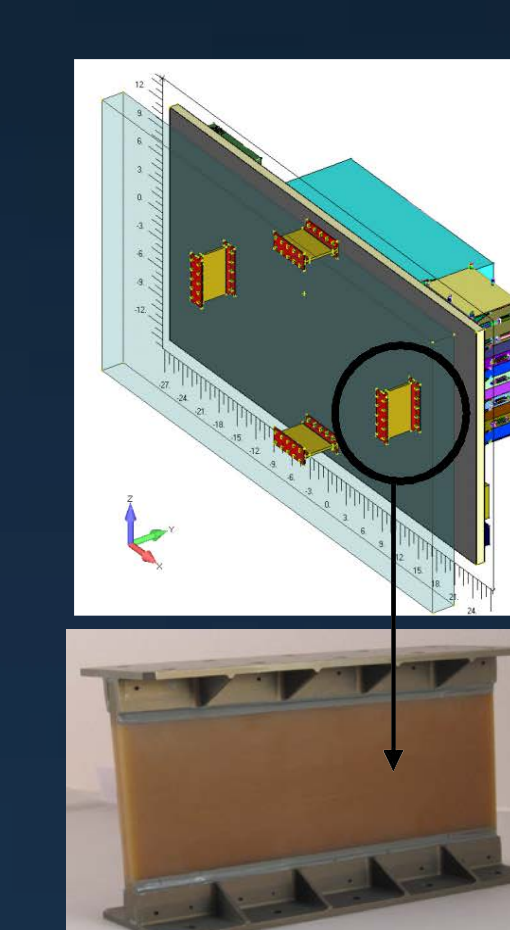
LHP with Bypass Valve



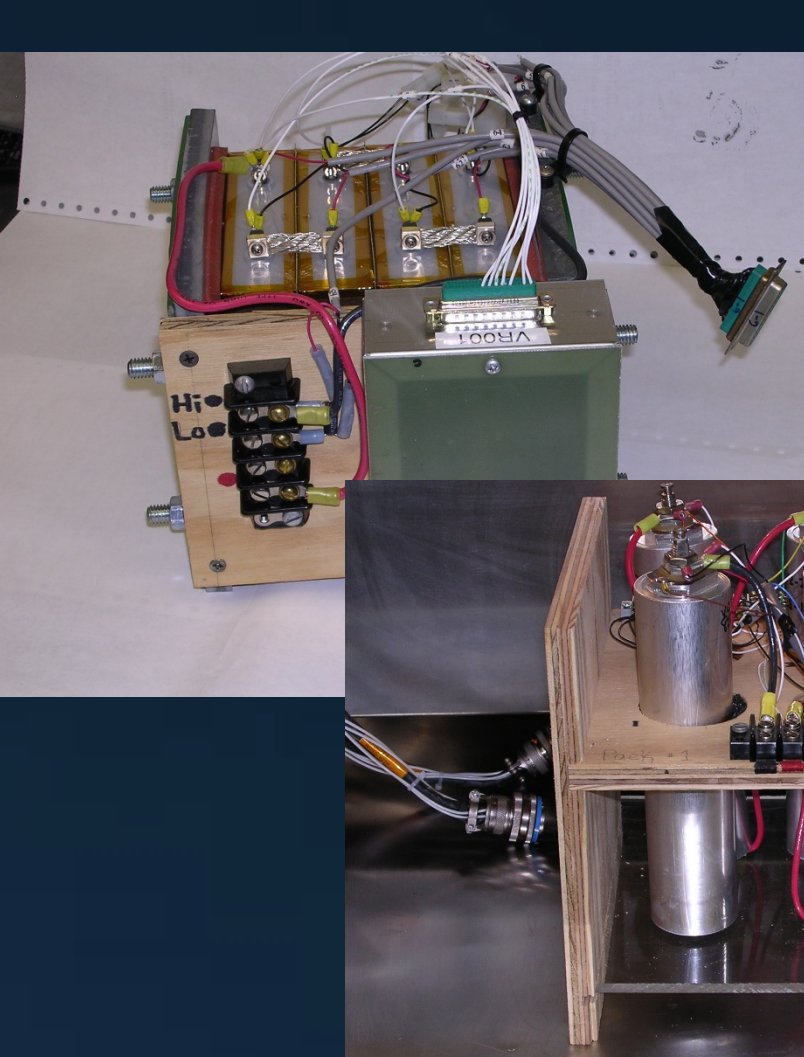
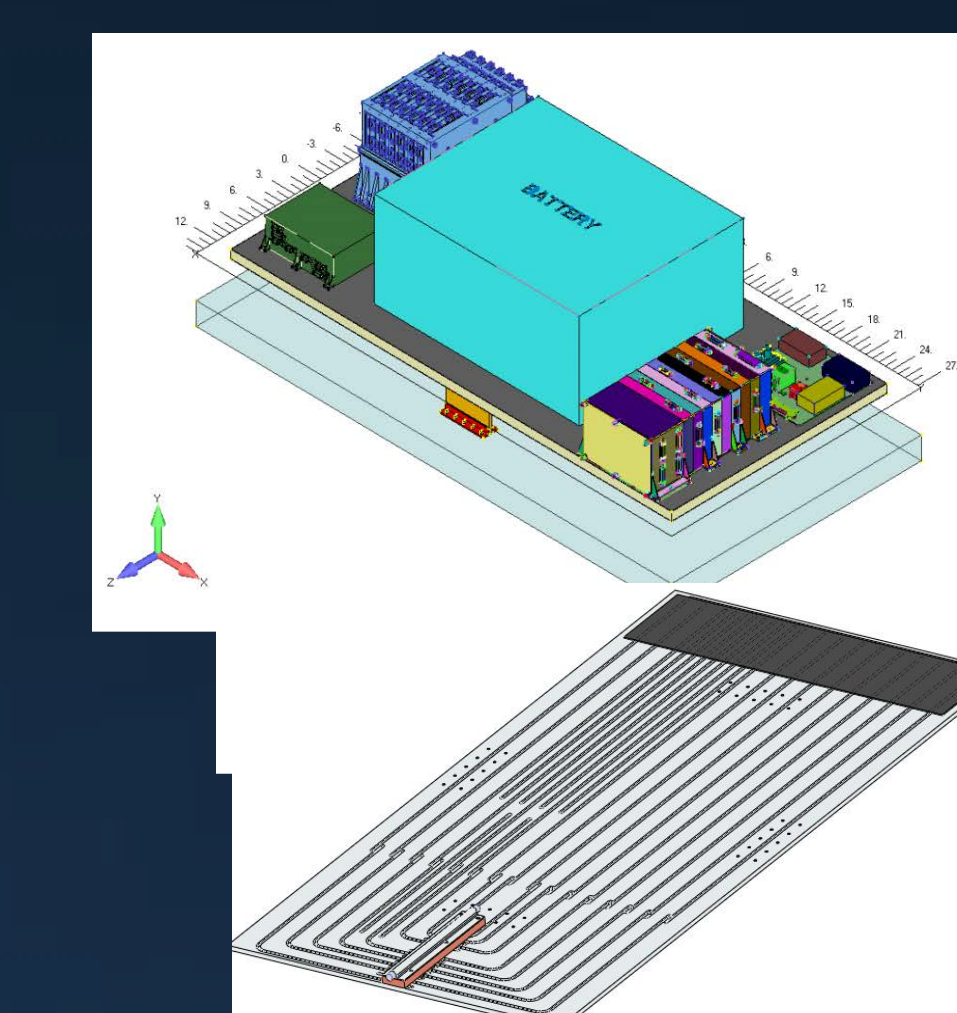
Baseline Orientation



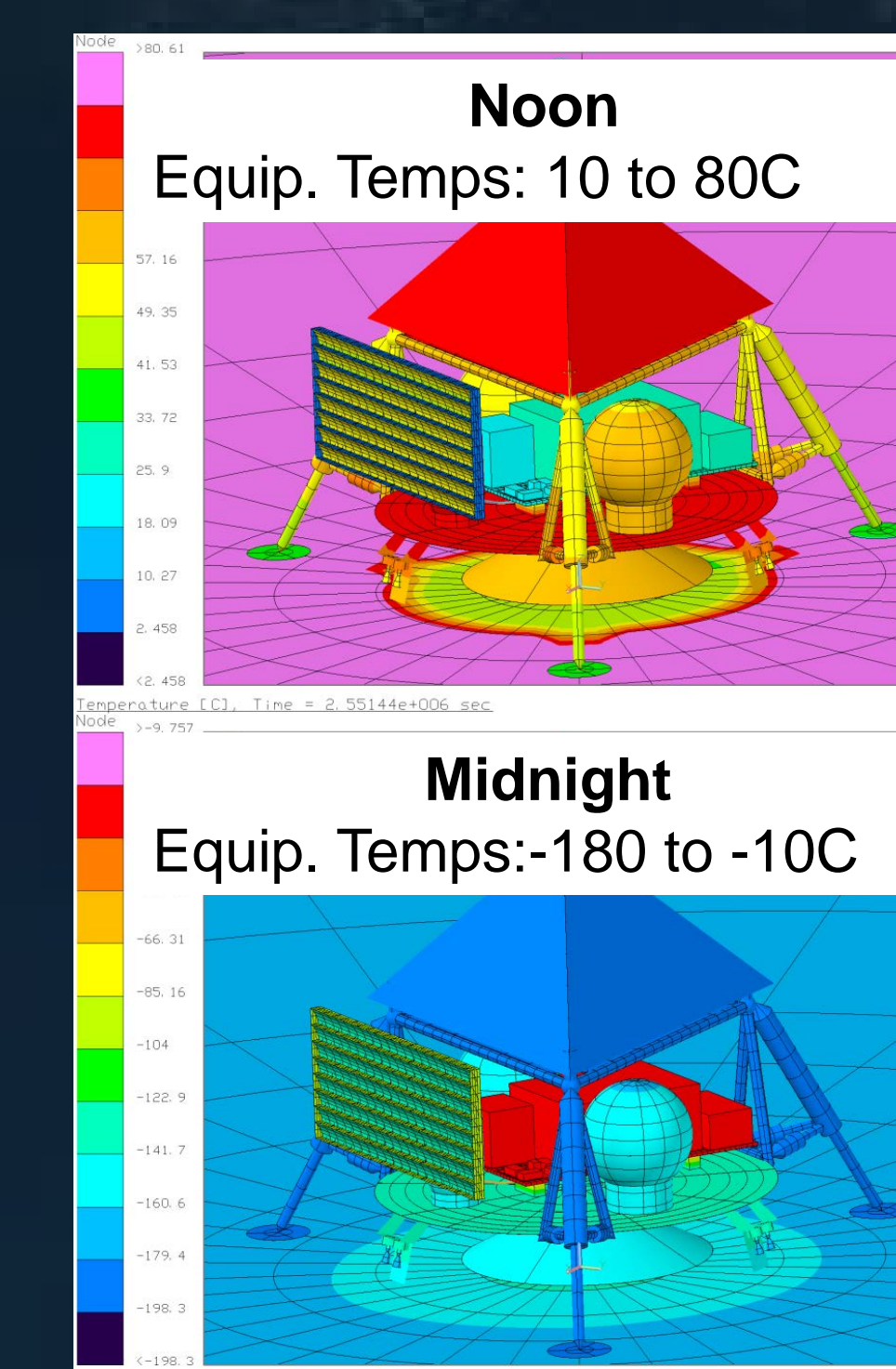
Lander Design/Risk Reduction Activities



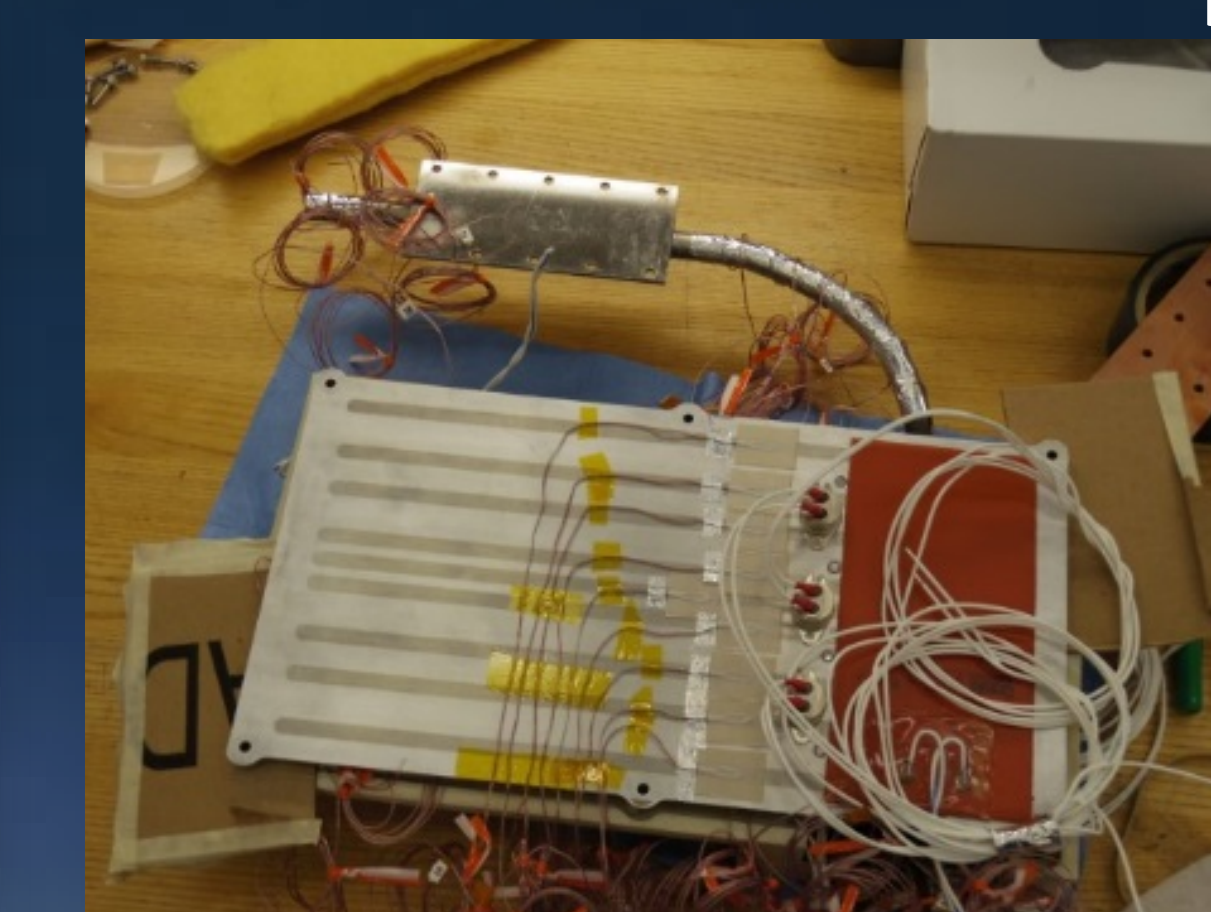
Analysis/Testing of Baseplate & Thermally Isolating Structures



Battery life testing at temperature



Integrated Thermal Analysis



Integrated thermal system testing on ground & on ISS

Bottom Line: Analysis & testing of passive variable heat transport approaches & system level risk reduction activities show viability of lunar night survival

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VCHP – Variable Conductance Heat Pipe

