THERMAL INNOVATIONS FOR EXTENDED-DURATION LUNAR OPERABILITY & SURVIVABILITY.

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Introduction: The desire for extended-duration robotic exploration of the moon without radioisotopes has highlighted a need for improved thermal capabilities. Described herein are a number of key thermal innovations resulting from three JPL-led projects: (1) Reverse-Operation DTE Thermal Switch (ROD-TSW); (2) Architecture for Thermal Enclosures of Moon Instrument Suites (ARTEMIS … *unrelated to NASA ARTEMIS*); and (3) Planetary and Lunar Environment Thermal Toolbox Elements (PALETTE). ROD-TSW and ARTEMIS were funded by JPL while PALETTE, which concludes in FY23, is funded by NASA GCD.

Problem: Multi-day/night operability/survivability of lunar instruments, rovers, landers, and other systems is an extremely challenging thermal problem due to the ultra-low 50-100 K temperatures during the lengthy (15 Earth day) lunar night combined with ultra-high 350-400 K temperatures (at low-to-mid latitude sites) during the similarly lengthy (15 Earth day) lunar day.

Improvements: Lunar operation/survival without radioisotopes is achievable with conventional solar power and battery technology as long as thermal capabilities in four key areas are improved upon: (1) passive variable conductance thermal links; (2) low sink temperature radiators; (3) radiative thermal isolation; and (4) conductive thermal isolation. Also required (in concert with these improvements) is a new lunar strategy.

Strategy: First-generation CLPS landers were not designed for lunar night survival. Hence, the science payloads (SPs) they carry are similarly limited. To overcome this limitation, JPL is incorporating cubesat-based C&DH, solar power, telecom, and batteries into their lunar SP designs. With this strategy (and above improvements) any SP, lander, or rover can survive lunar night.

Innovations: The innovations needed to implement the improvments and strategy mentioned above include: (i) thermally-switched enclosures (TSE); (ii) parabolic reflector radiators (PRR); (iii) spacerless multilayer insulation (SMLI); (iv) low conductance thermal isolators (LCTI); (v) reverse-operation DTE thermal switches (ROD-TSW); (vi) miniaturized loop heat pipes (mini-LHP); and (vii) Vectran tension cable (VTC) supports.

Thermally-Switched Enclosures (TSE): The basic TSE places all temperature sensitive equipment within an internal housing (IH), which is supported from an external housing (EH) by tension cables. IH heat flow to a low sink temperature radiator is modulated by a passive variable conductance thermal link (VCTL). Improved conductive and radiative isolation are respectively provided by tension cables and spacerless MLI.

Parabolic Reflector Radiators (PRR): At low latitudes, CLPS lander-independent SPs with zenith-facing solar panels will need side-facing PRRs. Described herein is a two-piece PRR prototype developed on PALETTE that is: (a) highly affordable, because its two pieces are 3D-printable; and (b) capable of achieving a 230 K sink temperature when side-facing from a CLPS lander deck at a low latitude lunar site.

Spacerless Multilayer Insulation (SMLI): The primary way a TSE can provide extreme radiative isolation is by a new concept known as spacerless MLI. In this concept, nested boxes of double aluminized Mylar (DAM) are hung from the tension cables. With just eight layers, spacerless MLI from the PALETTE project was able to provide an e* value of 0.0015, which outperforms conventional spacecraft MLI by 13 times.

Low Conductance Thermal Isolators (LCTI): The PALETTE project investigated several options for LCTIs but in the end selected a low thermal conductivity 3D-printable polymer design. Three different materials (machinable Ultem 1000 and 3D-printable Ultem 9085/Ultem 1010) in two different sizes (short and tall) were tested. Per isolator conductance test values of 0.0005-0.001 W/K met the PALETTE target threshold.

Reverse-Operation DTE Thermal Switches (ROD-TSW): The ROD-TSW[1] utilizes DTE between a low CTE, low k rod and a high CTE (low or high k) body to create a fully passive 2500:1 ON/OFF ratio thermal switch. Two offshoots include an extended stroke version (ES-ROD-TSW) for non-vacuum and 13000:1 ON/OFF in vacuum, and a miniaturized version (mini-ROD-TSW) that is 30 g w/ length/width of 2 US dimes.

Minaturized Loop Heat Pipe (mini-LHP): To span the IH-EH space with the smallest cross-sectional area possible (from its two 1.6 mm OD lines), a 20 W propylene mini-LHP by Boyd Corp. is used. Propylene allows radiators to operate to 90 K without freezing.

Vectran Tension Cables (VTC): The cube-shaped IH is supported from the cube-shaped EH by eight corner high strength VTCs supplied by Applied Fiber. These nearly off-the-shelf cables provide about 32 kN of ultimate strength at a nominal diameter of 6.35 mm.

Mission Infusion: Five missions targeted to implement these innovations include: (1) Farside Seismic Suite (FSS); (2) Lunar Surface Electromagnetic Experment (LuSEE-Night); (3) Lunar Crater Radio Telescope (LCRT); (4) Lunar Geophysical Netowrk (LGN); and (5) Lunar Vector Helium Magnetometer (LVHM).

References: [1] Bugby, D. C. and Rivera, J. G. (2020) *ICES-2020-145*.