NASA SBIR 2021 Phase I Solicitation

Z2.01 Spacecraft Thermal Management

Lead Center: JSC

Participating Center(s): GRC, GSFC, JPL, MSFC

Scope Title:

Spacecraft Thermal Management

Scope Description:

NASA seeks new technologies that will facilitate low-mass and highly reliable thermal control systems for the exploration of our solar system. This solicitation specifically targets proposals for new technologies and methods that clearly address one of the following areas:

- Novel three-way valves that can operate to either mix or split single-phase fluid flow passively.
- Lunar lander/surface asset thermal technologies.
- Embedded cooling of power electronics.
- Concepts for closed-loop extravehicular activity (EVA) thermal systems.

These areas are considered of equal priority, and no award preference is expected for one area over another.

Passive Three-Way Valves

NASA seeks novel three-way valves that can operate as either a mixing valve (two liquid input ports and one liquid output port) or splitting valve (one liquid input port and two liquid output ports) that can be used to passively control loop temperatures by the degree fraction of radiator bypass. Such miniature passive thermal control valves could find use in a number of single-phase mechanically pumped fluid thermal control systems. Proposed technologies must address the following design goals:
- Design shall autonomously operate without power.
- <0.1% flow rate through the shutoff port, with a goal of having a provision for no leakage/adjustable leakage through the use of a pre-installed orifice.
- Control range of 5 to 10 °C, with pre-adjustable setpoint control.
- Operational temperature limits -55 to 90 °C, nonoperational limits of -55 to 125 °C.
- Designs shall be compatible with FC-72 working fluid as well as with those used on the International Space Station (ISS) thermal control loops (water and ammonia). Retrofit of soft goods is acceptable.
- Mass desired <250 g (maximum mass 500 g).
- Unit volume <50 cm³ (maximum 100 cm³).
- Leak rate $1 \times 10^{-6}$ scs/s gHe at 200 psia.
- Minimum 4,000 full actuation cycles, desired 17,500 cycles.
- Rad hard to 300 krad.
- 200 psia maximum expected operating pressure, 200 psia proof pressure, 800 psia burst pressure.
- Pressure drop <1.5 psi at 1.5 L/min of FC-72 working fluid.

**Lunar Surface Thermal Technology Development**

NASA is seeking focused efforts to develop large human-class lunar lander technologies. Technologies should address a gap associated to long-duration habitation on the lunar surface, where temperatures range from -193 °C or lower in shadow regions (including night) to 120° C at the equatorial subsolar point. System technologies should be orientation insensitive; for example, lander side-mounted radiators must provide their function regardless of lunar surface temperature condition. Technologies are needed that allow a single vehicle design to operate in all these environments. Technologies should address reduction in mass, volume, and power usage relative to current solutions. Adding heaters can lead to increased vehicle mass due to additional power generation and storage requirements and are not considered a novel architecture approach. Proposed radiator technologies should also address micrometeoroid and orbital debris (MMOD) robustness and protection potential where appropriate.

Examples of other challenges to address in this area include the deposition of dust on radiators leading to degraded optical properties, contamination-insensitive evaporators/sublimators to enable long mission life, and self-healing coolant tubes for MMOD-impact resilience. Technologies should be suitable for use in medium-sized landers that operate near 1-kW average heat dissipation capacity.

Alternatively, technologies that utilize the conditions provided by the lunar environment to provide a critical function may also be considered; for example, air-water separator technologies that leverage the gravity field of the lunar surface, or concepts that explore the viability of utilizing the lunar surface regolith to provide long-duration thermal control function. As appropriate, such systems should also address functional capability in the microgravity environment that will be experienced prior to lunar surface operations.
Proposed technologies should also be extensible to human-class landers that will have variable heat loads and average loads between 2 and 6 kW. All technologies should support a minimum flight duration of 5 years and be compatible with the encountered aerospace environment.

This subtopic is different from S3.06 subtopic, which is focused on thermal control technologies for payloads and smaller robotic landers. Technologies directly applicable to that scale vehicle should consider reviewing the S3.06 Thermal Control Systems subtopic.

**Embedded Cooling of Power Electronics**

To optimize the performance of state-of-the-art power and propulsion systems, it is often advantageous to directly embed thermal control mechanisms within the packaged hardware. The key advantages are to enable a lower temperature drop between the heat source and heat rejection to allow for higher rejection temperatures, to remove heat from concentrated areas (avoid localized hot spots), and to provide more uniform temperatures within the electronics package. Applications for such technologies range from very high power nuclear electric propulsion (NEP) systems, to compact laser diodes, to embedded cooling of rotating equipment. Here we specifically desire concepts that have the potential to efficiently manage high-performance power electronics in common compact packages.

At the device level, applications such as low-inductance GaN packages rely on low thermal impedance heat-sinking strategies which also facilitate mechanical compliance and often electrical isolation. Current state-of-the-art thermal gap fillers have functional thermal impedances of 1.5 to 11 K/W for 12-mm$^2$ GaN devices with thermal transfer of 200 to 400 mW/mm$^2$ [Ref. 6]. Solutions that improve these thermal impedances values by >50% are sought.

At the system level, NASA has interest in the cooling of standard 3U boards to assist in the Advanced Modular Power Systems (AMPS) program. This program calls for semiconductor to circuit board power transfer of >200 mW/mm$^2$, circuit board to backplane interface >5mW/mm$^2$, and backplane interface through wedgelock rail >15 mW/mm$^2$ with minimum thermal impedance [Ref. 7].

Example solutions include but are not limited to single-phase liquid jet cooling, heat pipes, and evaporation techniques. Any proposed solution should consider the material compatibility with the heat source and heat delivery to the vehicle’s primary active thermal control system as well as any adverse effects on the cooled electronics. Here, solutions may consider integration with either a traditional single-phase (liquid) vehicle active thermal loop or a two-phase (liquid-vapor) mechanically pumped active thermal loop. Power requirements to operate active systems must be addressed with the goal to minimize power. The transient performance of the proposed mechanism should be considered within the scope of the award in order to identify any key limitations of the
Closed-Loop EVA Thermal Technologies

EVA thermal control has traditionally relied on the dissipation of water to space. The current suit relies on a water sublimator, whereas the next-generation exploration spacesuit will include a water evaporator. In either case, water is consumed at an average rate of ~1 lb/hr over the course of the spacewalk. Here, NASA seeks novel closed-loop EVA thermal control technologies that have general potential for integration into future iterations of spacesuit design.

Concepts should address the following key performance parameters, at a minimum:

- Nominal average heat rejection >350 W.
- Accommodate peak heat rejection of at least 700 W for 15 min, with little or no consumable loss.
- Support EVA duration of at least 4 hr, stretch goal of 8 hr.
- Demonstrate viability of integration with the liquid cooling garment operating at a minimum continuous temperature between 8 and 10 oC.
- Time to regenerate/recharge the system <12 hr.
- Any regeneration/recharge impacts to the spacecraft should be addressed within the scope of the award (vehicle mass, power, volume impact assessment).
- Mechanism power <20 W including any controller electronics.

*Expected TRL or TRL Range at completion of the Project:* 3 to 5

*Primary Technology Taxonomy:*
- Level 1: TX 14 Thermal Management Systems
- Level 2: TX 14.2 Thermal Control Components and Systems

*Desired Deliverables of Phase I and Phase II:*

- Analysis
- Prototype
- Hardware
- Software

*Desired Deliverables Description:*

Phase I awards in this area are expected to demonstrate analytical and/or empirical proof-of-concept results that demonstrate the ability of the organization to meet the goals stated in the solicitation.

At the conclusion of a Phase II contract, deliverables are expected to include a functioning prototype (or better) that demonstrates the potential to meet the performance goals of the technology. Any delivered math models should include supporting data that validates the assumptions used within the model.

*State of the Art and Critical Gaps:*
These focus areas strive to reduce mass, volume, and power of a thermal control system in the next generation of robotic and human-class spacecraft. Additionally, the exploration of embedded thermal control technologies may have a direct impact on the AMPS program in the near term and provide valuable insight into techniques for other embedded cooling applications. These improvements may come through either novel hardware solutions or modernization of software tools used to assess human vehicle interactions. The current state of the art in thermal control results in vehicle power and mass impact of greater than 25% to 30% due to old technologies still in use. Furthermore, as missions become more variable (dormancy, environments, etc.), the need for intelligent control (both actively and passively) within the thermal control system becomes more apparent. Science payloads will continue to decrease in size, increase in power, and require precise temperature control, all of which cannot be readily provided by traditional thermal control methods due to vehicle-level impacts of overall performance, mass/volume, and power.

Relevance / Science Traceability:

- Advanced Modular Power System
- Europa Clipper/Lander
- Lunar Lander
- Long-duration habitats (Moon, Mars, etc.)
- EVA

References:
