National Aeronautics and Space Administration

Two-Phase Thermal Control Technology

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Program: Strategic

Project Objective:

A strategic goal of the Engineering & Science Directorate is to develop advanced spacecraft technologies required for the next generation small spacecraft. Toward this goal, the objective of this task is to develop a two-phase thermal control system that can concurrently provide:

- Accommodation of increased heat densities associated with miniaturization
- Science-enhancing temporal and spatial temperature stability
- Efficient heat transfer across deployable interfaces and reclamation of waste heat for redistribution over long distances

This technology helps deep space missions to perform "decadal-class" science within the small spacecraft (from SIMPLEx to ~200 kg dry-mass-class) paradigm.

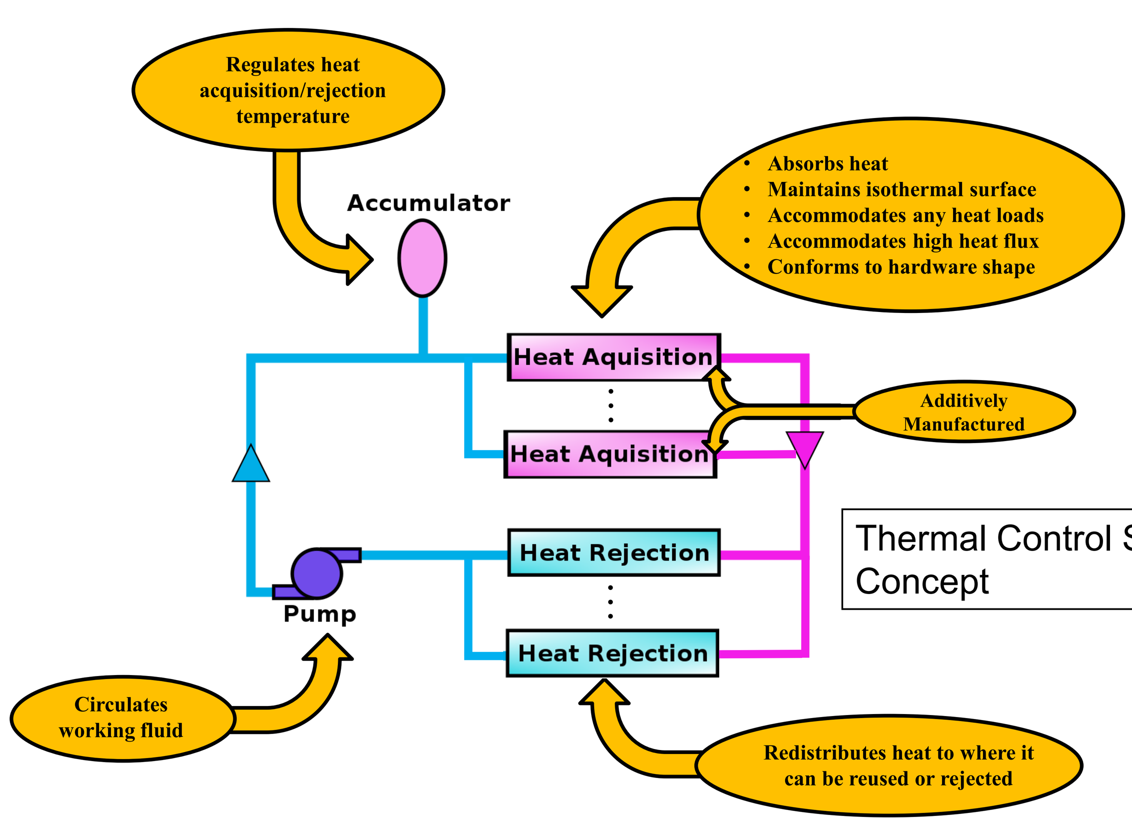
FY19 Results:

- Brassboard system test bed: The test bed has been completed and is currently operational. It includes precision flow meters for both single- and two-phase flow, pressure, temperature, and IR imagery data. Anhydrous ammonia is the working fluid, enabled through a rigorous safety compliance feature set.
- Micro-pump delivery and integration: A brassboard micro-pump was delivered by our external partner, Hamilton Sundstrand Space Systems, after a 2 year design and development process. This custom design utilizes hydrodynamic bearings to meet the 15 year life requirement. The low flow rates inherent with this loop technology was leveraged to design a pump that consumes very low electrical power (for every 205 Watts of waste heat transported, 1 Watt of electrical input power is required). The pump was integrated into the system test bed and is currently operating as expected.
- Advanced evaporators: Key to our loop architecture is the evaporator design. The second and third generation designs were integrated and run in the system test bed. Temperature oscillations encountered in the previous design iteration were solved, and precise temporal stability was achieved. High heat fluxes greater than 10 W/cm^2 were accommodate with a total power of 1 kW applied. Notable improvements in spatial isothermality were also demonstrated.
- Modeling and analysis: Analytical work was focused to those specific areas where enhanced heat transfer occurs. The modeling capability is being developed to serve as a design tool. This tool will then be used to better leverage the manufacturing capabilities afforded by the 3D printing of metallic evaporators.

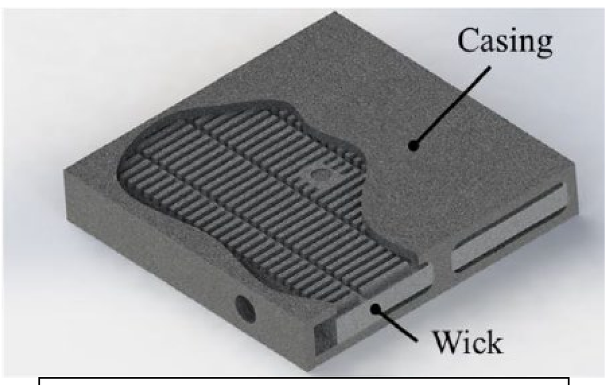
Benefits to NASA and JPL (or significance of results):

The proposed thermal control system will position NASA and JPL with unmatched thermal control capability and will uniquely position us for economical spacecraft missions to the outer planets, inner planets, and asteroids. The system architecture accommodates multiple heat sources ranging from standard bus electronics to the most demanding payloads in terms of thermal stability. The proposed system is highly reconfigurable. Thermal flight rule restrictions are minimized using autonomously load balanced multi-view radiators. I&T costs are reduced using field joints for plug-and-play configurability and scalability. The use of latent heat provides unmatched isothermality and heat transfer when compared to single-phase systems. The minimization of power consumption for heating and temperature control afforded by this technology enables planetary science missions to the outer planets using a small, solar-powered spacecraft.

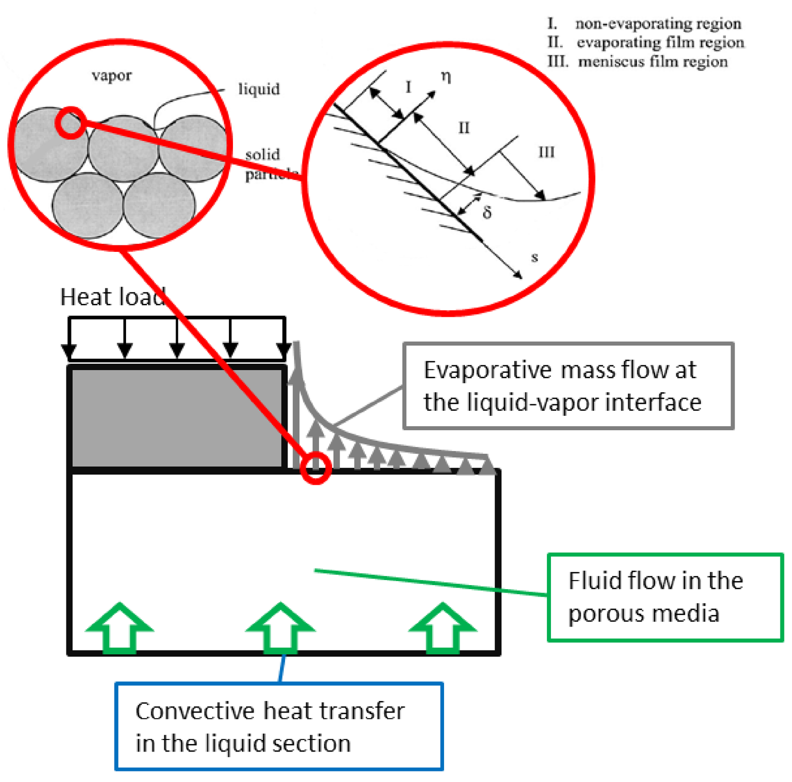
- Provide > 15 year life
- Accommodate mounting interface heat fluxes as high as 15 W/cm^2
- Reduce electrical heater power needs by 10X
- Provide precision temperature control to < 0.05 ^{o}C/min (< 0.05 ^{o}C/10hr goal) using < 10 W of thermal control power
- Reduce thermal hardware mass by 50%
- Maintain isothermicity of a 1-meter class payload bench to < 2 ^{o}C
- Provide radiator turn-down capability of > 500:1 and remove the need for louvers and heat pipes



Thermal Control System Concept



Additively Manufactured Heat Acquisition Device (evaporator)



Heat transfer mechanism within the evaporator

Publications:

Eric Sunada, et al., "A Two-Phase Mechanically Pumped Fluid Loop for Thermal Control of Deep Space Science Missions," 46th International Conference on Environmental Systems ICES-2016-129, Vienna, Austria, July 10-14, 2016.

Benjamin Furst, et al., "Experimental Results: A Mechanically Pumped 2-Phase Ammonia Testbed for Thermal Control," 23rd Workshop on Thermophysics in Microgravity, El Segundo, California, March 2019.

Benjamin Furst, et al., "A Mechanically Pumped Two-Phase Fluid Loop for Thermal Control Based on the Capillary Pumped Loop," 49th International Conference on Environmental Systems, ICES-2019-50, Boston, Massachusetts, July 7-11, 2019.

Takuro Daimaru, et al., "Development of an Evaporator Using Porous Wick Structure for a Two-Phase Mechanically Pumped Fluid Loop," 49th International Conference on Environmental Systems, ICES-2019-325, Boston, Massachusetts, July 7-11, 2019.

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