FY24 Topic Areas Research and Technology Development (TRTD)

Loop Heat Pipes for Smallsat Swarms (LHPss)

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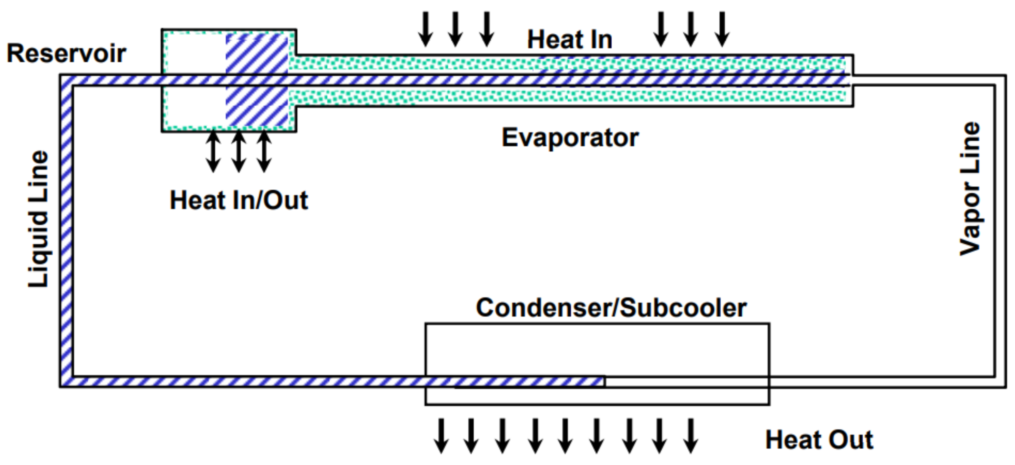
Strategic Focus Area: Thermal control systems

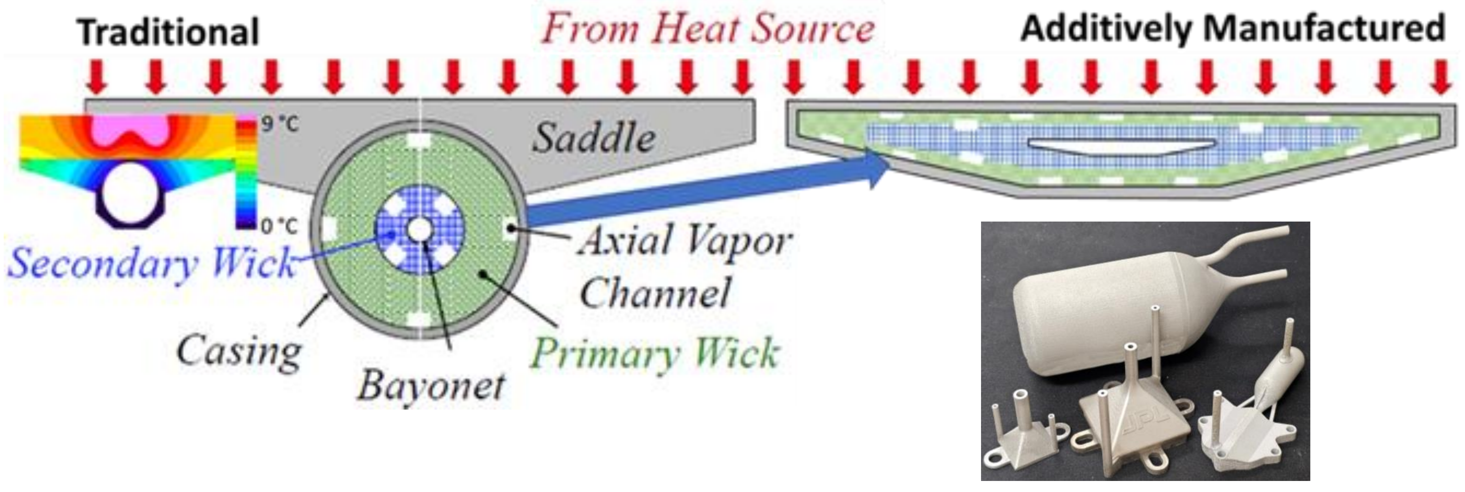
- ✔ Decrease Cost > 90%
- ✔ Decrease Lead Time > 90%
- ✔ Demonstrate Repeatability

Background: As JPL tackles ever increasingly complex and difficult missions, thermal management is consistently viewed as a possible bottleneck in mission success. From a probe accessing the interior oceans of Europa or Enceladus, robotic assets surviving extended durations in the permanently shadowed regions of the moon, Venus lander and sub-orbital science, or even Earth science missions seeking smaller and more powerful instruments, the ability to efficiently take in and route heat will be crucial to future mission success. Loop Heat Pipes (LHPs) represent the premier passive thermal transport system for spacecraft, are currently flying on hundreds of missions, including SWOT and TES on EOS/AURA (both JPL integrations), as well as GOES weather satellites and Boeing/Hughes 702 satellites. However, recent very high impact flight hardware failures, significantly high implementation costs and excessively long vendor lead times due to extended hardware procurement cycles involving complex integration of a half dozen precision engineered components (relying on highly sensitive, craftsman-dependent fabrication processes) have led to LHPs being seen as a high-risk component and are now viewed unfavorably by the flight community.



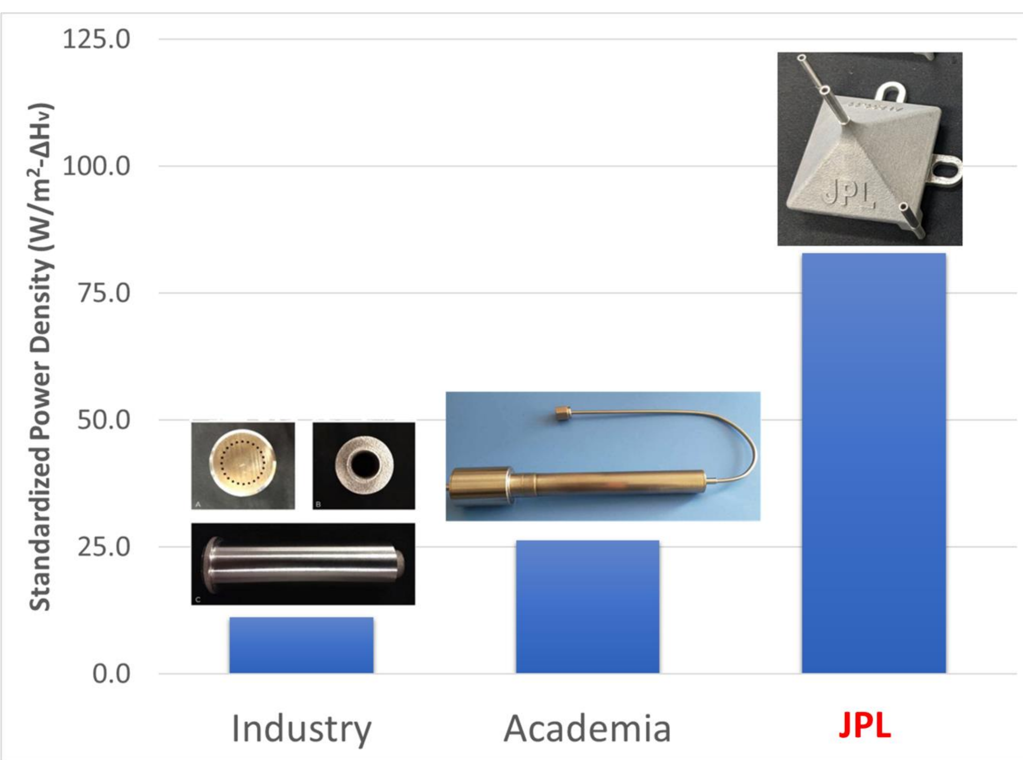
Left: A schematic of a typical loop heat pipe system. Only the evaporator is complex an expensive. All other parts are extruded tubing.

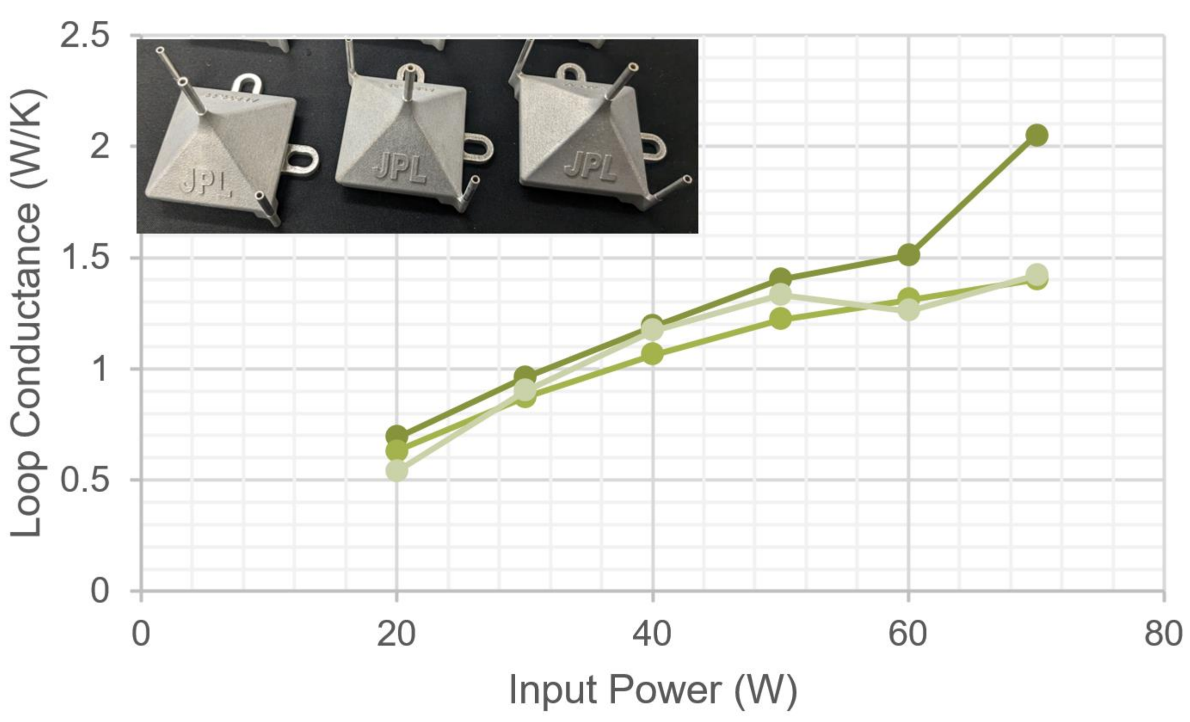
Right: The generic concept for transforming a traditionally manufactured evaporator into a monolithic additively manufactured system.

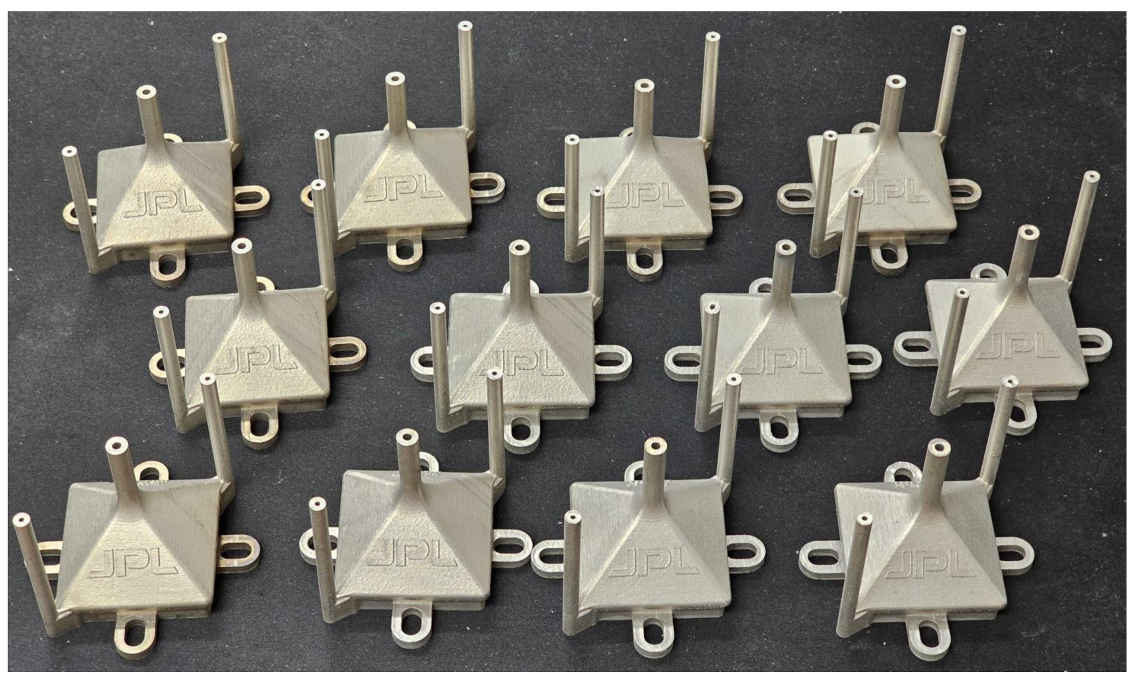


Approach and Results: In Year 1, we built a dedicated testbed for straightforward swapping of loop heat pipe evaporators. It enables keeping a single adiabatic and condenser length, as well as simplifying calculations for fill factors and performing charging. Acetone was chosen as our test working fluid due to its low operational pressure, low risk of health and safety implications, and relatively high latent heat. An overall design optimized for simplicity of printing, and not thermal performance, has been created and fabricated. Testing has been performed with startup, operation, and repeatability having been demonstrated by the end of fiscal year with a single-piece aluminum evaporator.

In Year 2 we fabricated & tested a number of test geometries. Much of this work was performed by Kyle Piper, an exceptional undergraduate from Caltech. Starting in the summer of 2024, Takeshi Yokouchi, a graduate student from Tohoku University also joined the project team for six months. During the year, we performed a series of thermal tests across a handful of aluminum and titanium evaporator models and porous geometries. These were all performed in a gravity-favorable orientation, similar to how they would be integrated on a planetary science lander such as a distributed lunar seismological network or CLPS lander. Performance was found to exceed state of the art for published systems from both academia & industry, with cost-per-evaporator being less than $5k each compared to $500k for state of the practice systems. Lead time was decreased to a month from a year, and repeatability of performance across multiple builds was demonstrated within experimental uncertainty. Aluminum evaporators were found to suffer significantly from heat leaks across the wick, so a modified geometry was developed. Titanium had less heat leak, and showed superb operation. Inconel 625 variants were received at the end of the FY and will begin testing soon. A design integrating a secondary wick for microgravity (or counter-gravity) operation has also been developed. This FY's work has led to two NTRs in preparation, as well as two papers.







Significance/Benefits to JPL and NASA: We have demonstrated the feasibility of additive manufacturing to reduce part count, decimate cost and schedule requirements, enhance performance, and have superior repeatability compared to industry standard manufacturing techniques. These will enable top tier thermal management techniques at prices lower than vastly inferior technologies for future JPL missions and instruments. The technique is also scalable, allowing it to be used for swarms, disposable missions (sounding rockets, balloon, etc), or providing dedicated thermal management for individual subsystems.

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Publications:
Two publications in preparation
Two NTRs in preparation

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