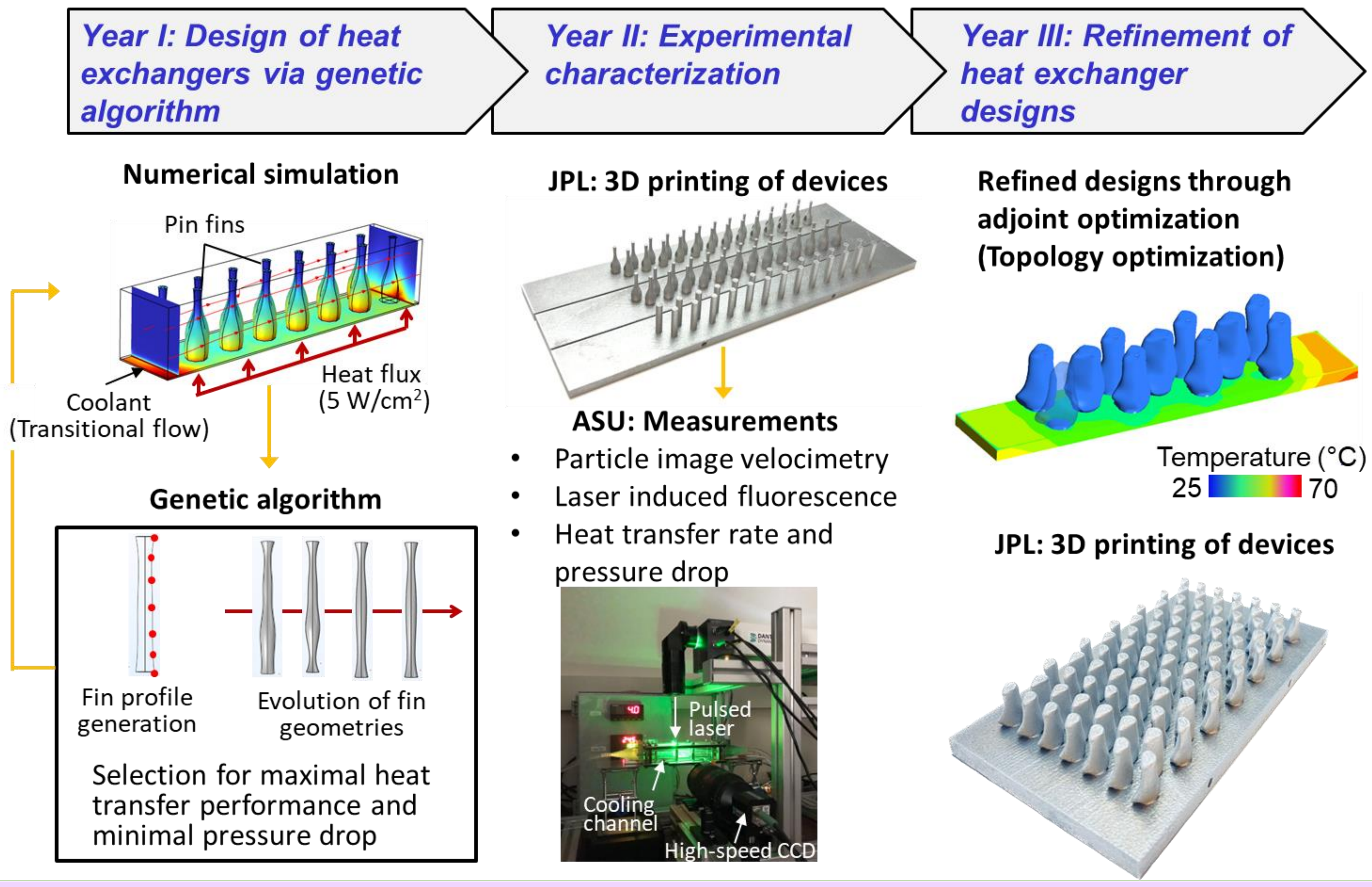
National Aeronautics and Space Administration

FY24 Strategic University Research Partnership (SURP)

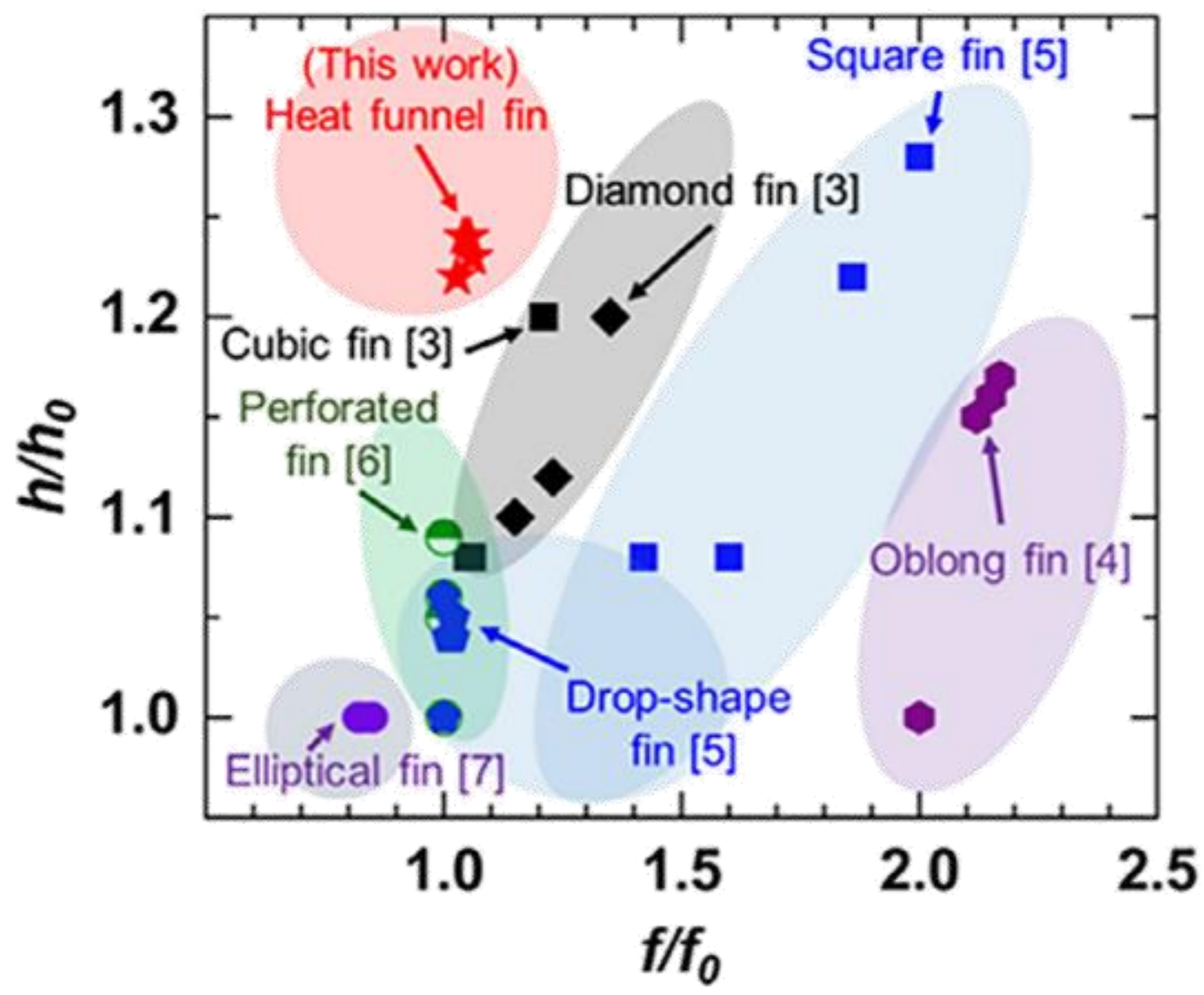
3D Printed Heat Exchangers with Creative Internal Patterns

Principal Investigator: Elham Maghsoudi (353) & Scott Roberts (357)

Co-Investigators: Nam Phong Nguyen (Arizona State University), Beomjin Kwon (ASU)



Objective: The objective of this research is to develop 3D printed heat exchangers with creative internal patterns for Mechanically Pumped Fluid Loops (MPFL) to increase the heat rejection performance to pressure drop by a factor of 3 while reducing the weight greater than 20%. Collaboration between JPL additive manufacturing and thermal experts and ASU 3D Energy Device Lab will improve performance of MPFL. MPFL used on Mars Science Lab (MSL), and M2020 Landers, and upcoming Europa Clipper mission to reject the heat during the cruise stage and maintain the electronics temperature within allowable flight temperatures.



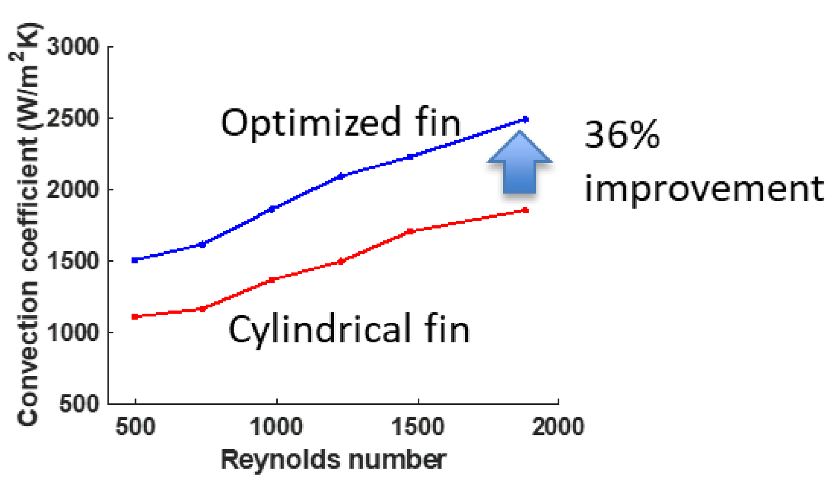
Background: The current-state-of-the-art fabrication includes manual and long lead items such as tube bending, fit check tubing, hand welding, etching, priming, and epoxy bonding the tubing to the heat exchanger. Using current 3D printing techniques such as Ultrasonic Additive Manufacturing, UAM, or Direct Metal Laser Sintering, DMLS, will not only reduce the fabrication lead time and labor cost, also increase the effective heat transfer between the working fluid and the heat exchanger plate by eliminating the epoxy bond. Moreover, the designs of legacy heat exchangers were not derived by accounting for the geometric design freedom of 3D printing techniques. This project aims to optimize the heat exchanger designs by exploring a large design space that is enabled by the 3D printing techniques. Numerical optimization, an emerging design method for thermofluidic devices, will be employed to investigate unexplored internal patterns for heat exchangers.

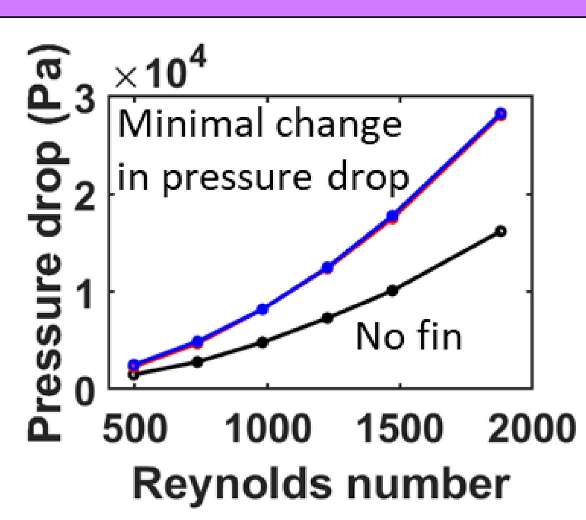
Approach & Results: In year 1, the project optimized the shape of pin fins integrated into a cooling channel using the genetic algorithm (GA). The pin fin designs generated by the GA were evaluated by two different methods: (1) three-dimensional (3D) CFD simulation and (2) random forests (RF) machine learning (ML) model. We compared the designs generated by the two design evaluators and explore the opportunities with GA-assisted optimization. It was found the genetic algorithm was able to rapidly optimize the performance of a pin fin with minimal computational resources (several minutes on a desktop computer vs hours on a cloud cluster). Ultimately, it provided similar-to-better performance than a standard CFD methodology.

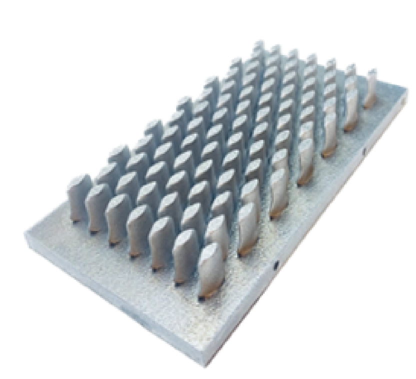
In the second year a testbed was developed to measure fluid flow, heat transfer, and flow visualization tools. These were used to perform measurements on 3d printed polymeric coupons, single pins, as well as additively manufactured Al6061R2 from JPL's Additive Manufacturing Center. The optimized pins provided a ~20% better transfer of heat from the plate into the fluid as compared to the state of the practice pins. The performance was at roughly the same amount of pressure drop, meaning no additional pump power would be required over current standard JPL techniques (or equivalent heat transfer could be accomplished for significantly less power).

Our third year revisited designing pins, with more intricate designs and deeper optimizations of each individual pin in the flow path. This was only achievable due to the genetic algorithm's speed of performance, being able to accomplish in an hour what would take a traditional CFD technique longer than a month. Coupons were fabricated and tested, and performed even better than designs from Year 2, reaching a ~35% improvement over standard pins while maintaining a similar pressure drop.

Significance & Benefits to JPL/NASA: The impact to JPL is the development of a novel solution to introduce new generation of heat exchangers with higher performance. These can be integrated into ground support equipment, Mars missions, long duration lunar rovers, or any other project utilizing heat transfer between a fluid and a solid.







One more design will be tested in September 2024.

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PI: Scott N. Roberts
scott.n.roberts@jpl.nasa.gov
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Publications:

1. Nguyen, NP; Maghsoudi, E; Roberts, SN; Kwon, B. "Shape optimization of pin fin array in a cooling channel using genetic algorithm and machine learning."
2. Nguyen, NP; Maghsoudi, E; Roberts, SN; Hofmann, DC; Kwon, B. "Understanding heat transfer and flow characteristics of additively manufactured pin fin arrays through laser-induced fluorescence and particle image velocimetry."
3. *In Preparation*: Nguyen, NP; Maghsoudi, E; Roberts, SN; Kwon, B. "Multi-step adjoint optimization approach for designing pin fin heat sinks."

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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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