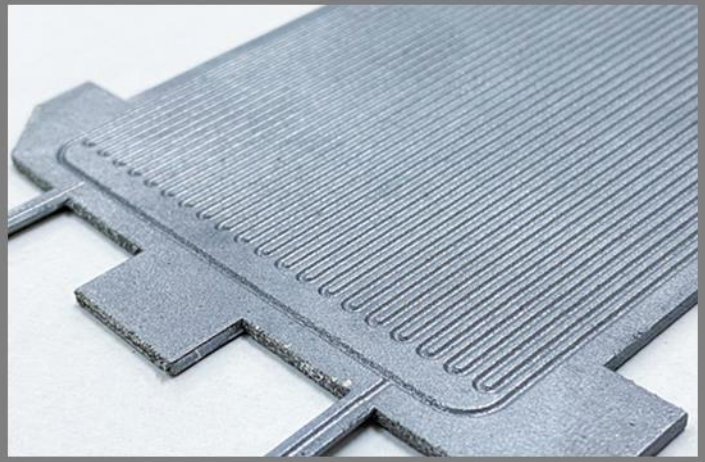
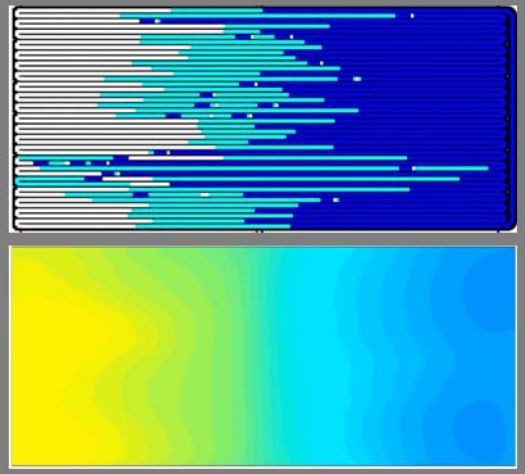
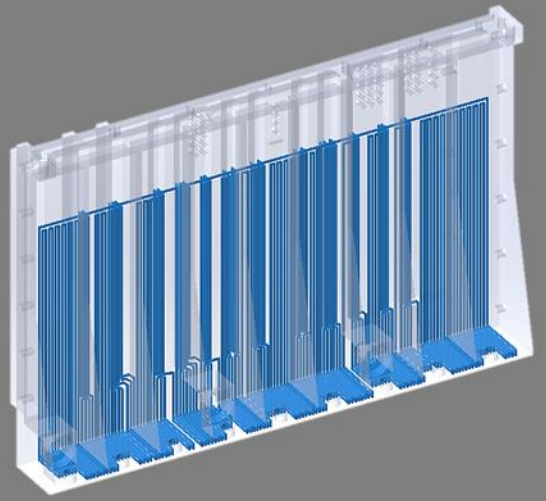


ADDITIVE MANUFACTURED
OSCILLATING HEAT PIPE (OHP)



HIGH PRECISION
THERMAL-FLUID
NUMERICAL SIMULATION



THERMAL-STRUCTURE
MULTI-FUNCTIONAL SYSTEM

Virtual Research Presentation Conference

Multi-functional Oscillating Heat Pipe System for High-Density Heat Management

Principal Investigator: Takuro Daimaru (353K)

Co-Is: Scott Roberts (357H) Andre Pate (357D) Eric Suh (356C) Ben Furst, Stefano Cappucci Kieran Wolk, Kimi Odagiri (353K), Stefano Morellina (353F) Eric Sunada (353A)

Program: Topic

RPC-172

Jet Propulsion Laboratory
California Institute of Technology

Introduction

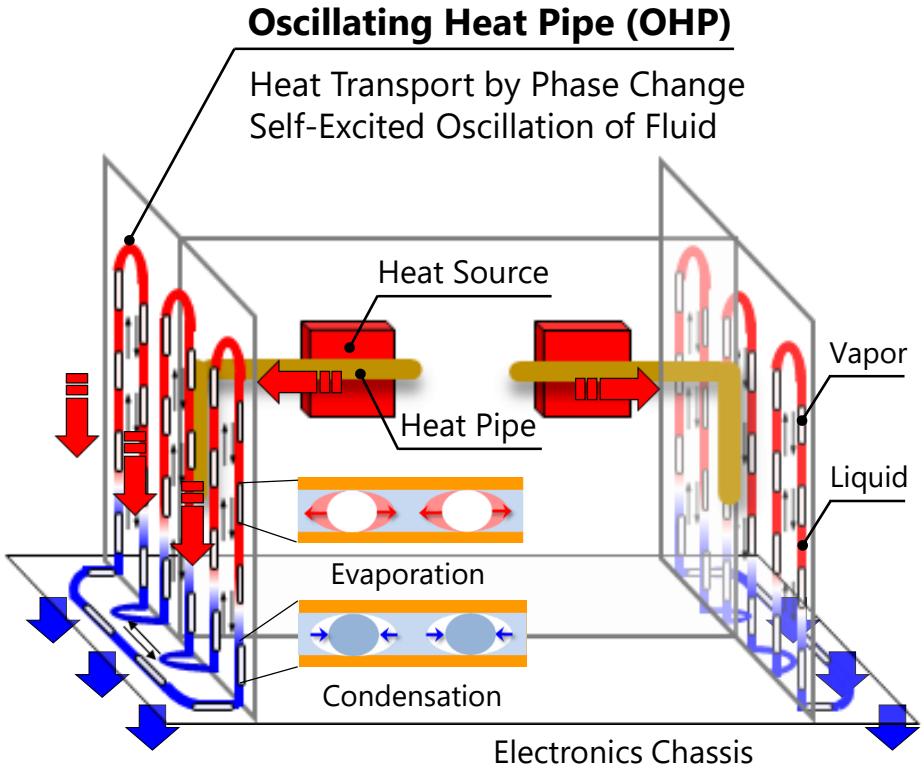
Abstract

An OHP is a new type of heat pipe technology which transports heat by evaporation and condensation of fluid. The self-excited oscillation occurs when heat is applied to the OHP. This oscillation enhances the heat transfer by creating thin liquid film on the tube wall surface.

We propose a 10x increase in heat transport versus a traditional heat pipe (100s W/cm2 vs. 10s W/cm2). By integrating OHPs directly in a truly multi-functional structure, thermal interface resistances are removed and freedom to optimize the geometry is gained. This thermal-structure multi-functional system can provide high heat transfer rates from the electronic component.

In this project, one of world's first additive manufactured OHP was successfully fabricated and tested. Also, a high precision thermal-fluid numerical simulation model was developed. Finally, multi-functional OHP systems for high heat density electronics is proposed.

Multi-functional Oscillating Heat Pipe System



Problem being solved:

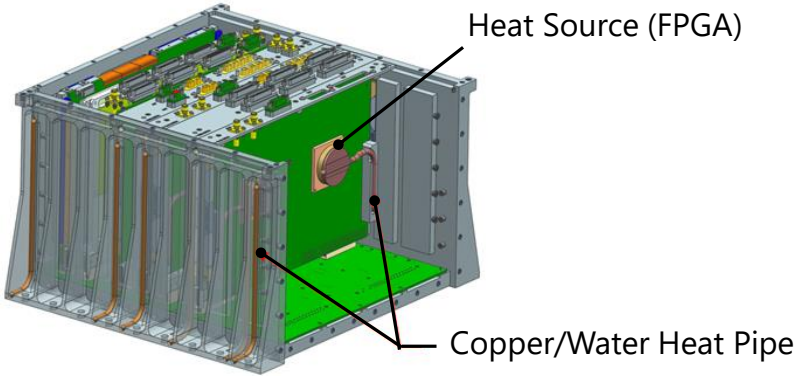
- Very-High Heat Density Electronics Cooling
  - Low Margin, Capability-driven Operation
  - Ex.) FPGA on OCO-3, SWOT, Mars2020

Comparison with State of the Art

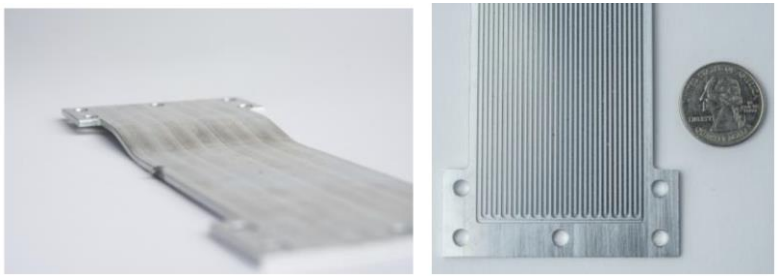
- SoA within JPL: **Copper / Water Heat Pipe**
  - Lower Performance / 1-D Heat Transfer
  - Problem on Freeze/Thaw Cycle due to Sintered Wick
- SoA outside JPL: **Flat-plate Shape OHP**
  - JAXA and AFRL, On-orbit Experiments
  - Limited in Flat-plate Shape/Simple Channel Pattern
- This Project: **Additive Manufactured OHP**

Why this is important to JPL

- Increase Flexibility to Add More Functions to Devices
  - Without Increasing Thermal Subsytem Mass and Volume
  - Thermal and Structural Multi-Functional System



Current Electronics Chassis in JPL



Flat-Shape OHP Developed by AFRL

Methodology

1) Establish Additive Manufacturing Method

- Mini-Channel by Additive Manufacturing
- **Enables Complex 3D Channel Configuration**

2) OHP Proto Type by Additive Manufacturing

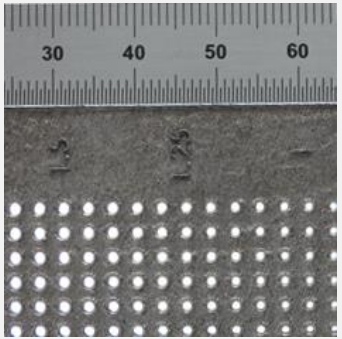
- Flat-Plate OHP Proto Type
- **One of World's First Results**

3) Development of High Precision Numerical Model

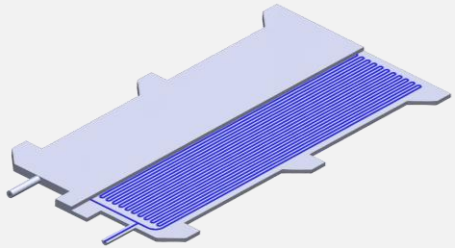
- Extend Original 1D OHP Model to 3D Heat Transfer
- Validation by Experimental Data
- **Enables Performance Prediction**

4) Propose Multi-Functional OHP System

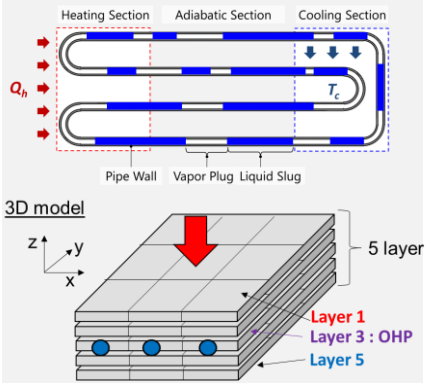
- 3D Channel Configuration to Accommodate Heat Source
- Using Numerical Simulation as Design Tool



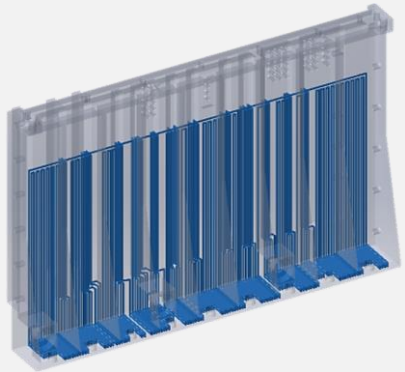
1) Manufacturing Method



2) OHP Prototype



3) Numerical Model



4) Multi-Functional OHP System

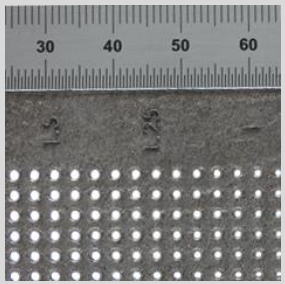
Results: 1) Establish the Manufacturing Method

Step 1: Smooth Surface Development

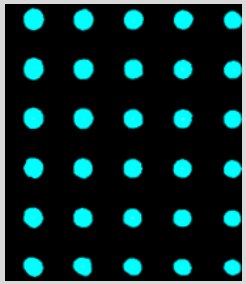
Coupon of AlSi10Mg

- Print Direction
- Laser Power
- Laser Spot Size
- Scan Speed

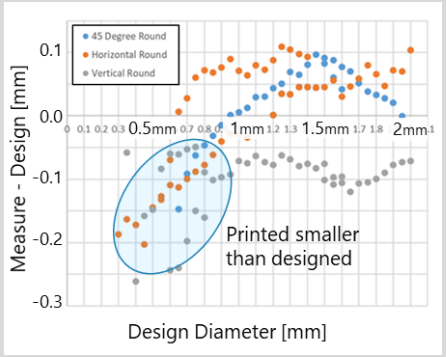
Step 2: Chanel Size Measurement



Printed Coupon

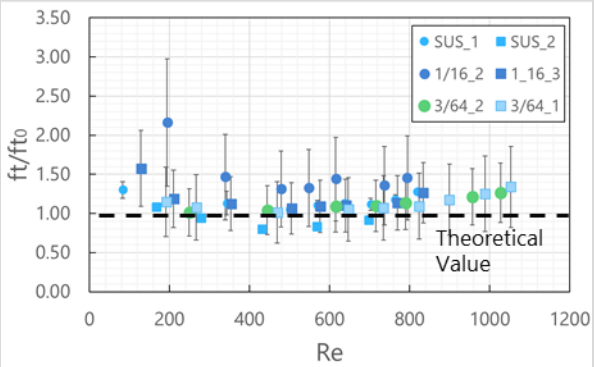


Analysis



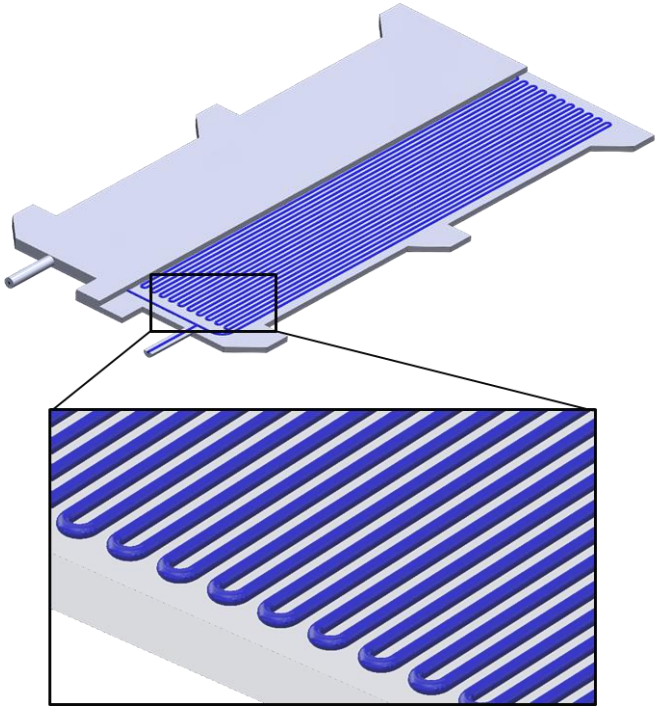
Design vs Printed

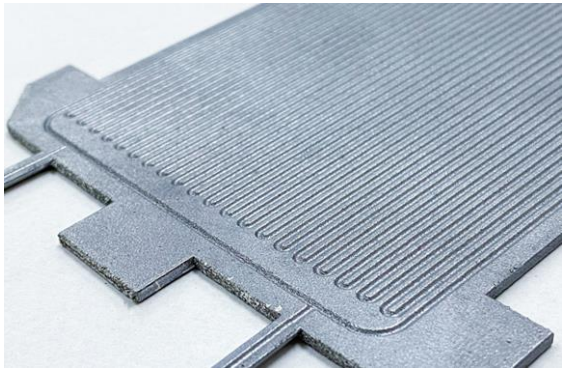
Step 3: Pressure Loss Measurement

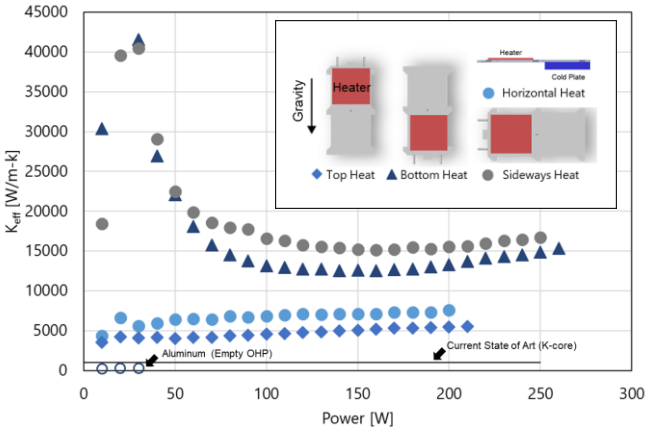


- **Manufacturing method of mini-channel by additive manufacturing was successfully established.**

Results: 2) OHP Prototype by Additive Manufacturing







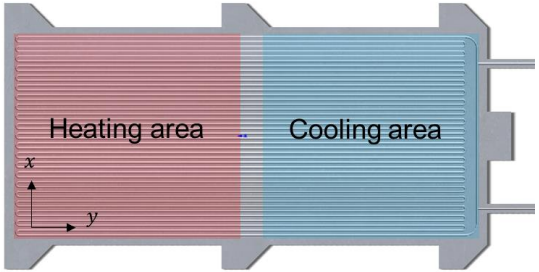
- Material : AlSi10Mg
- Number of Turns : 42
- Chanel Diameter : 1 mm
- Turn Radius : 1 mm
- Plate Length : 20 cm
- Plate Width : 9 cm
- Plate Thickness : 4 mm

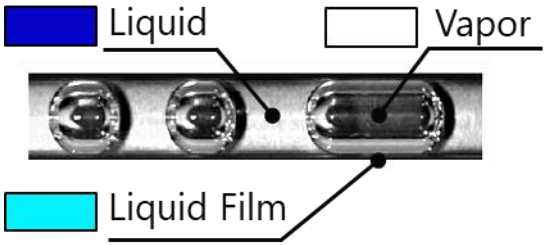
- **One of world's first Additive manufactured OHP was successfully fabricated and tested.**
- **Effective thermal conductivity of 7500 W/m/K (Horizontal orientation) is 47 times higher than Aluminum Plate.**

Results: 3) Develop High Precision Numerical Model

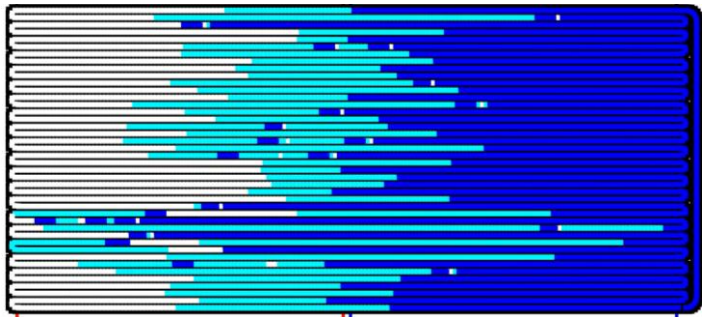
100 W

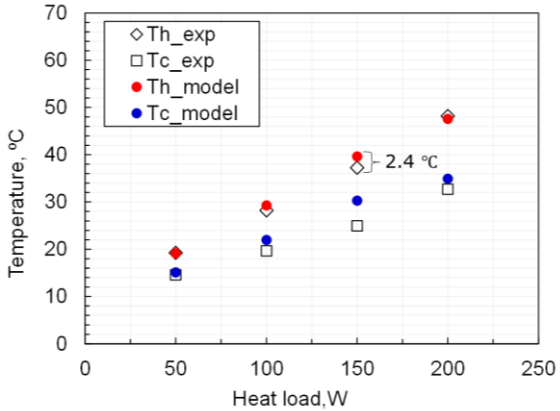
Time = 30 sec
Steady-state
1.0 x speed



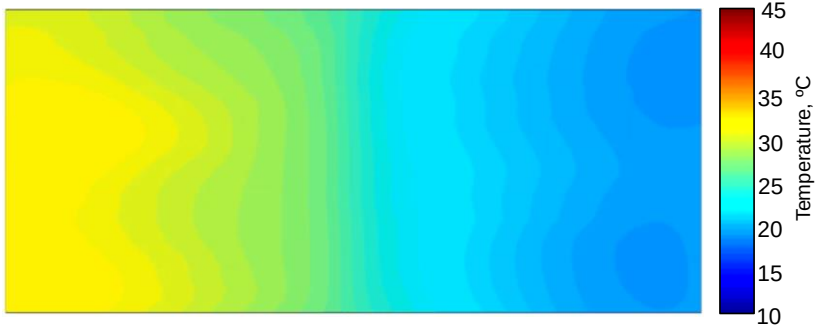


Change in liquid-vapor distribution



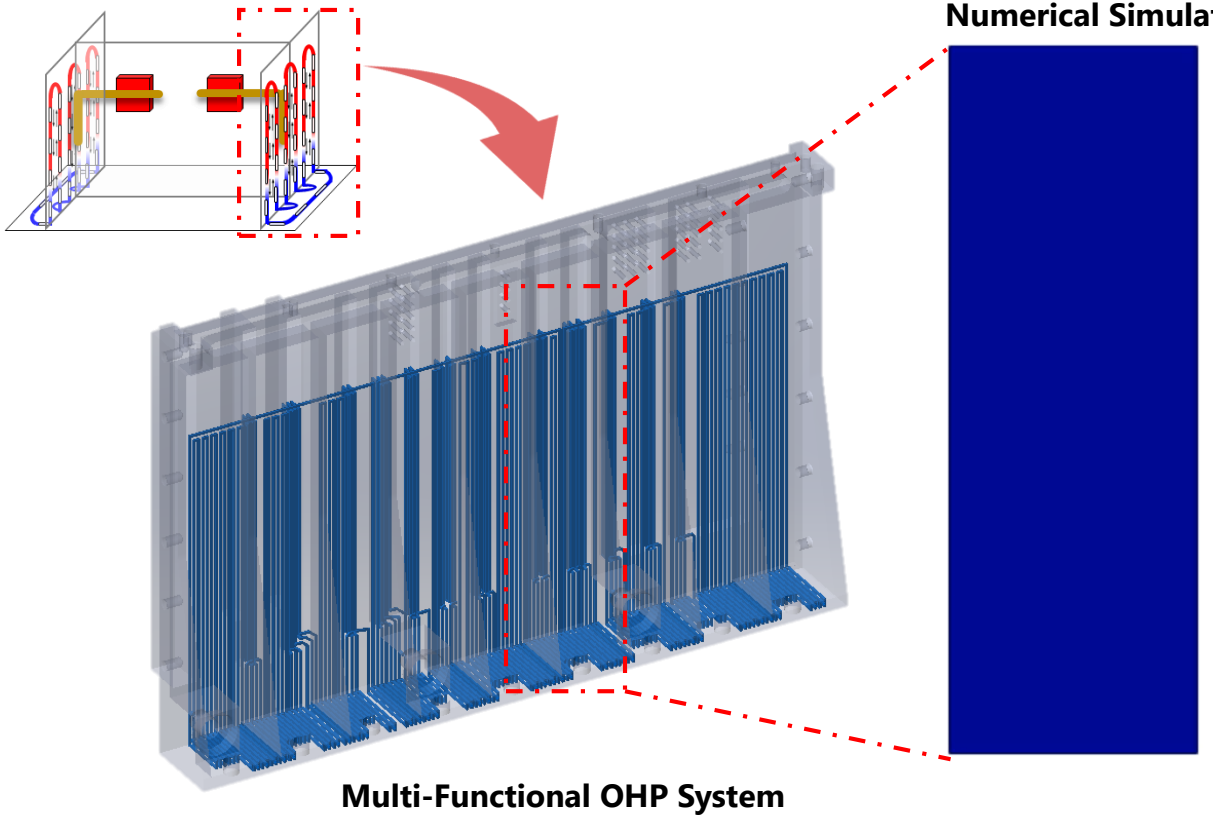


Change in temperature distribution



- **Precise OHP numerical model with 3D heat transfer was developed.**
- **Heat removal of 100 W/cm² was successfully simulated.**

Results: 4) Design Electronics Chassis with Embedded OHP

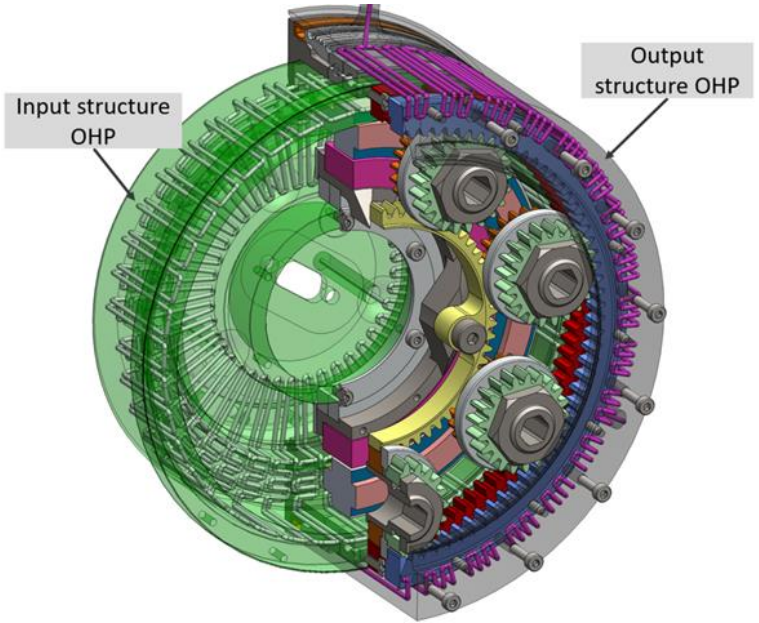


- **Multi-Functional OHP system was proposed and design was demonstrated by numerical simulation.**
- **Future Work:**
  Fabrication and test of proposed system.

Other Applications of Additive Manufactured OHP in JPL

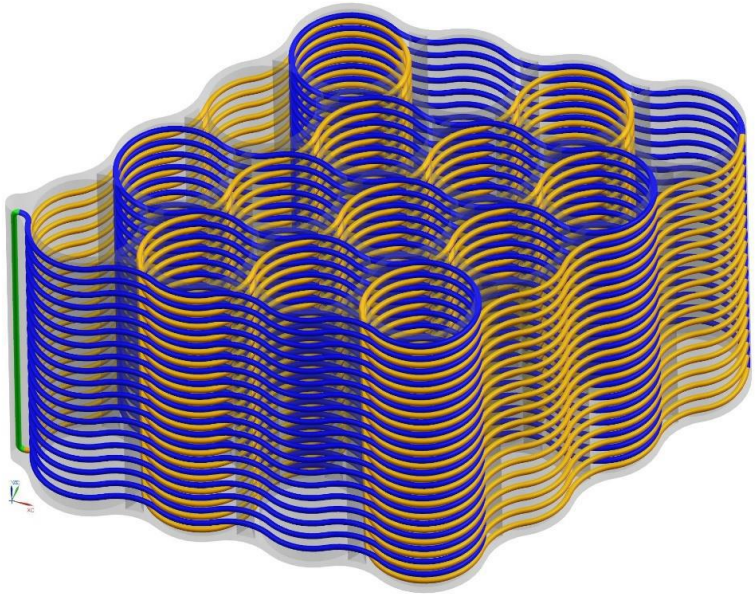
AM OHP for Actuator Thermal Management

Courtesy of Elham Maghsoudi (RPC-173)



AM OHP for Lithium-Ion Battery Case that Prevents Thermal Runaway

Courtesy of Benjamin Furst (RPC-174)



Publications and References

Journal Papers

1. Takuro Daimaru et al., “Development of an Aluminum Oscillating Heat Pipe via Additive Manufacturing,” Applied Thermal Engineering (In Preparation).
2. Kimihide Odagiri et al., “Numerical investigation on thermal characteristics of an additive manufactured aluminum oscillating heat pipe,” Applied Thermal Engineering (In Preparation).
3. Kimihide Odagiri et al., “Effect of thermal diffusivity of oscillating heat pipe material on heat transfer performance based on numerical analysis,” Applied Thermal Engineering (In Preparation).