3D Printed Actuators with Innovative Integrated Thermal Management

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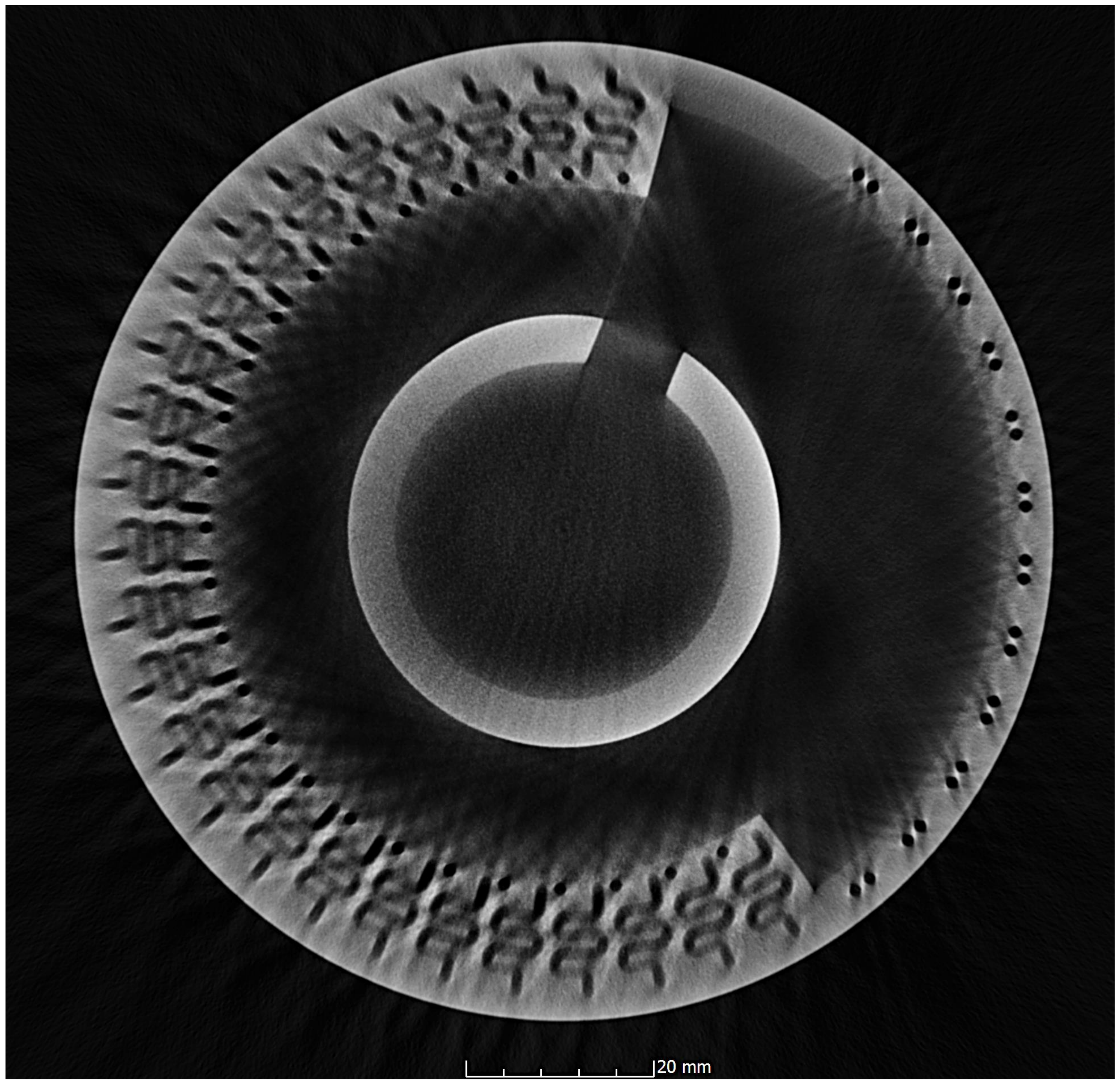
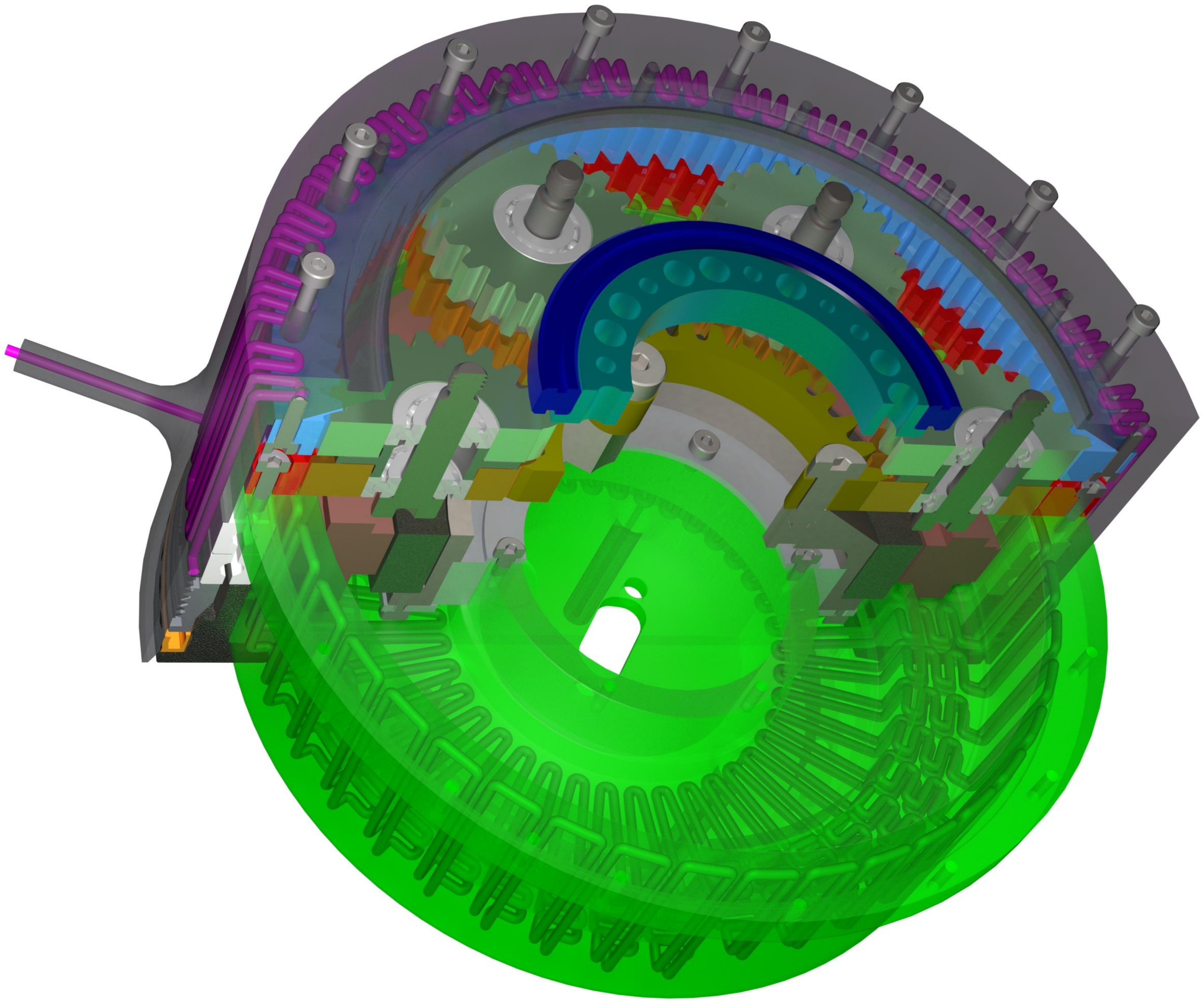
Program: FY21 R&TD Topics **Strategic Focus Area: Thermal control systems**





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Clearance Number:
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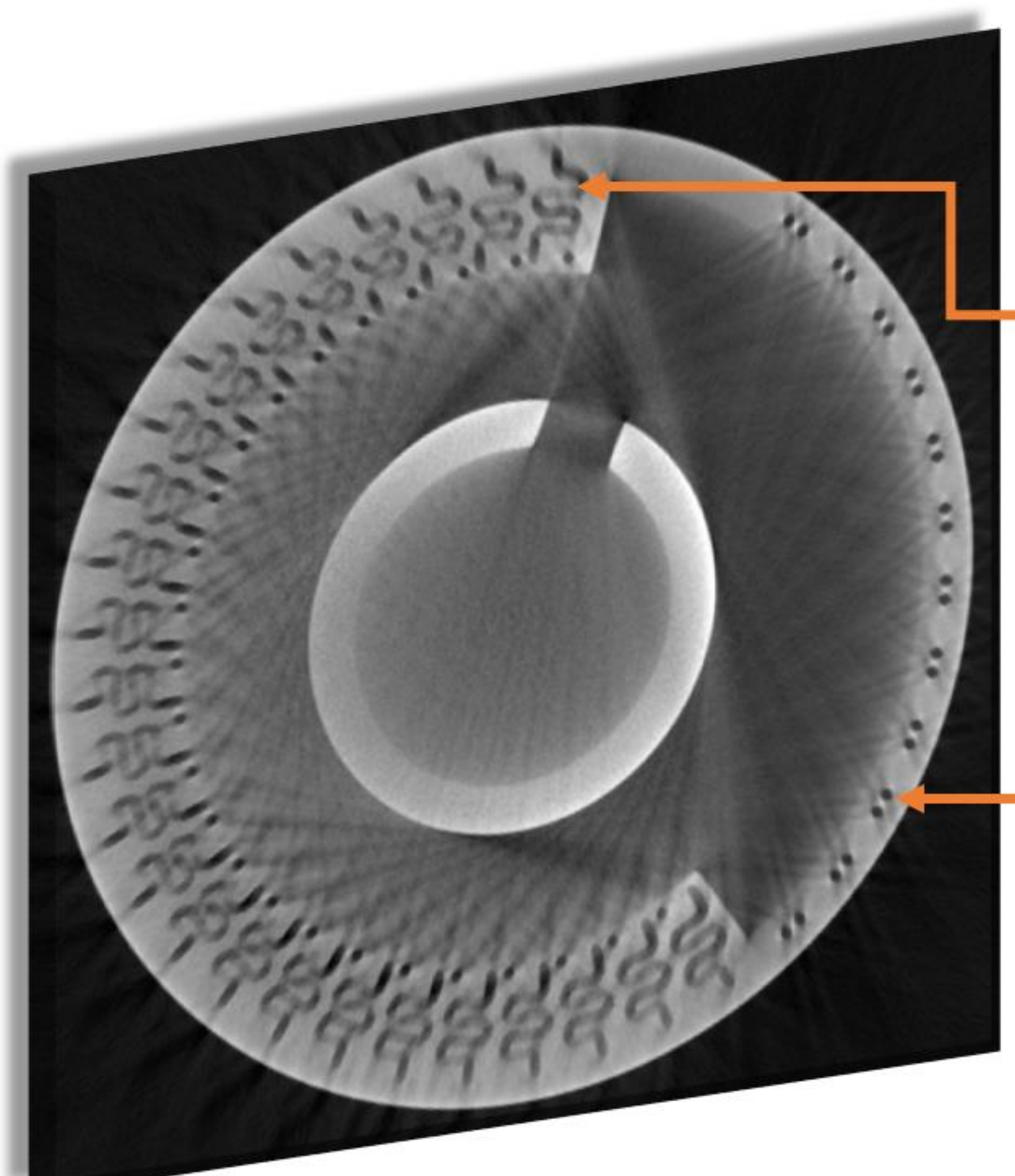
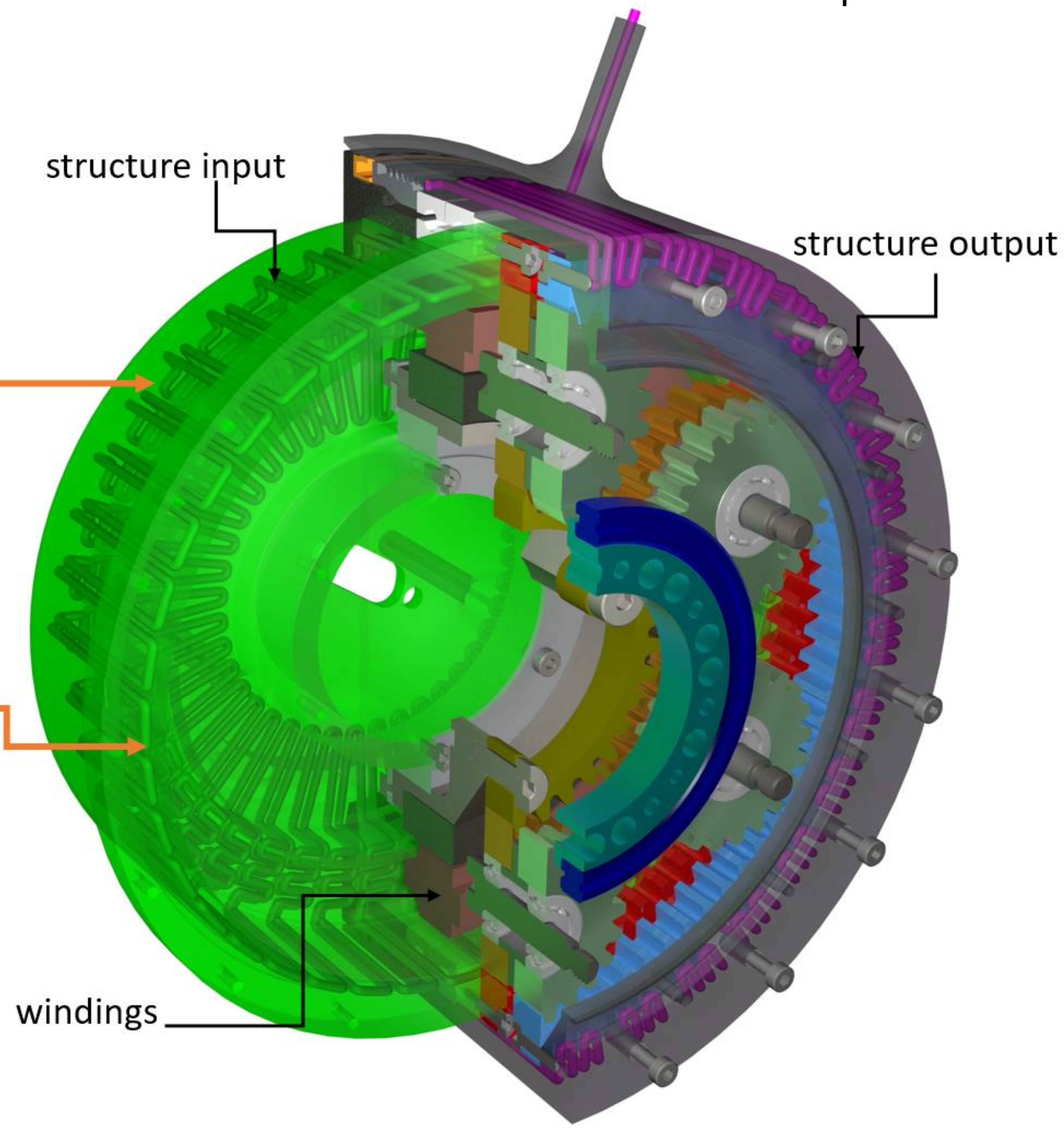
Background and Objectives

An electric actuator incorporating novel features for thermal management is designed and analyzed. Reducing intra-actuator thermal resistance is not only beneficial for cold missions (helping to pre-heat the gearbox) but can also enable high power applications in benign environments. The proposed design increases the thermal conductance between the motor windings and the motor casing by at least two orders of magnitude over the state of practice actuator designs. The design leverages Additive Manufacturing (AM) to integrate a complex 3 dimensional Oscillating Heat Pipe (OHP) directly within the actuator structure. An analysis of a proposed revised design incorporating OHPs into the input structure indicated 100 times improvement in thermal conductance over base material. Thermal enhancement leads to 10 times improvement in actuator power density.



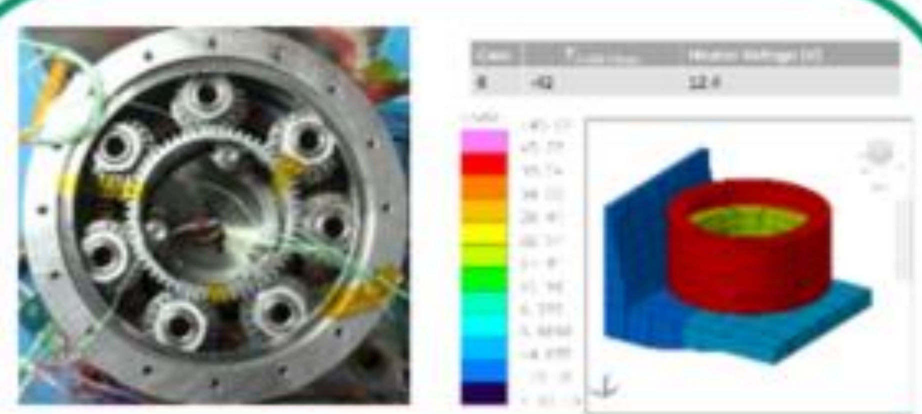
Actuator 2ϕ design



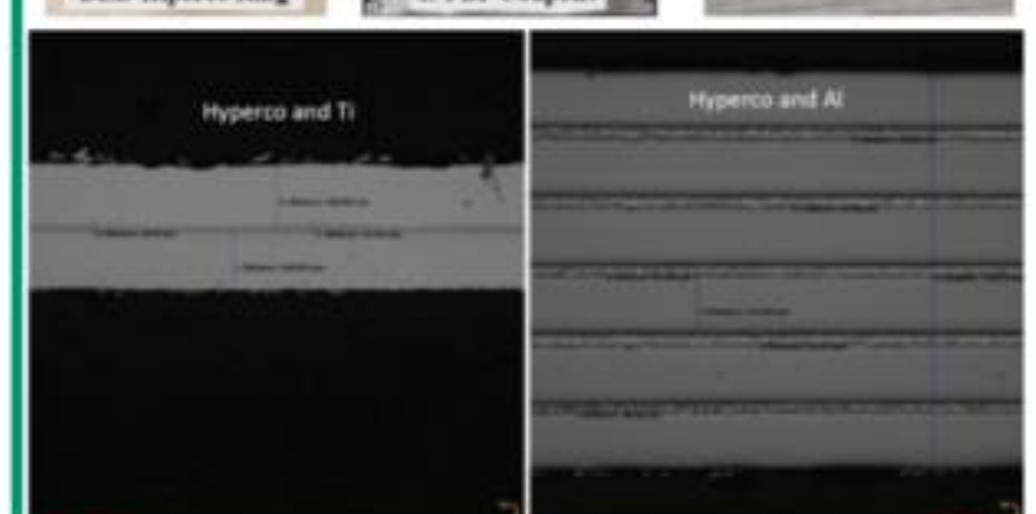
Approach and Results (1/5)

Methodology

FY19

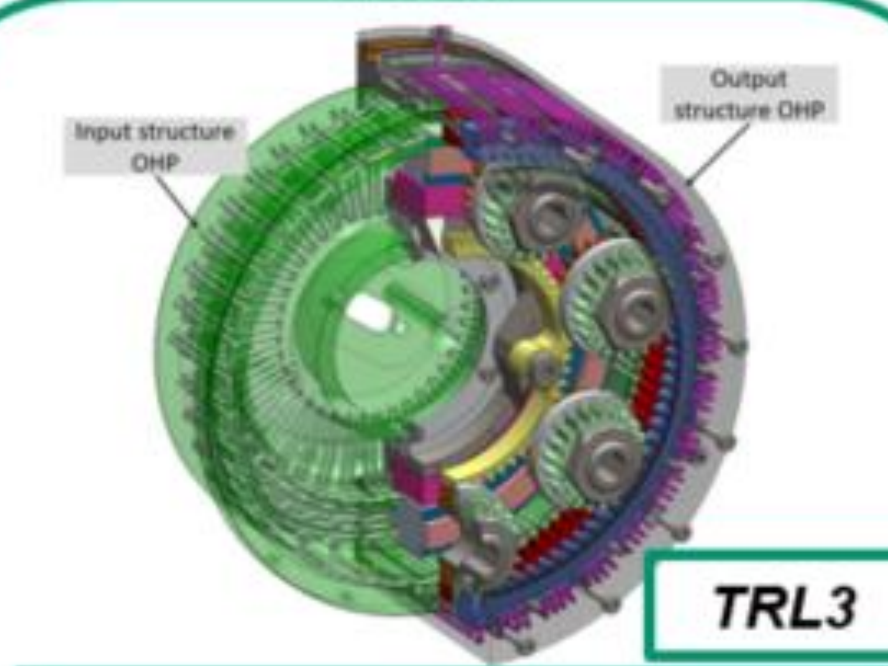


- Actuator baseline Design/hardware fabrication **TRL2**
- TVAC test and thermal model correlation



*Extensive testing and prototyping concluded that full laminate stack printing is not possible with today's technology.

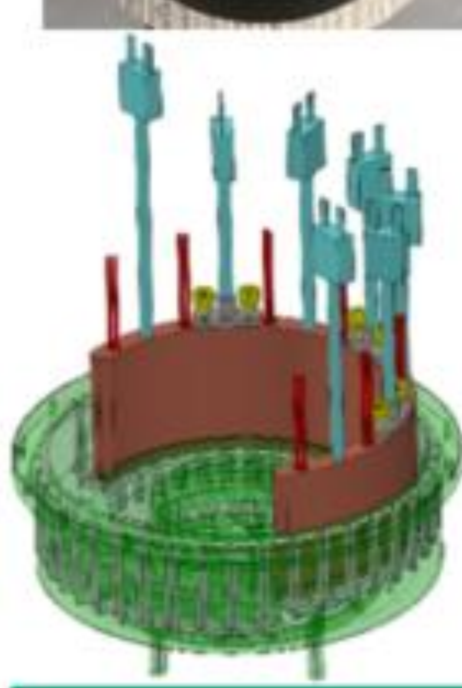
FY20



TRL3

Actuator 2ϕ design

TRL3

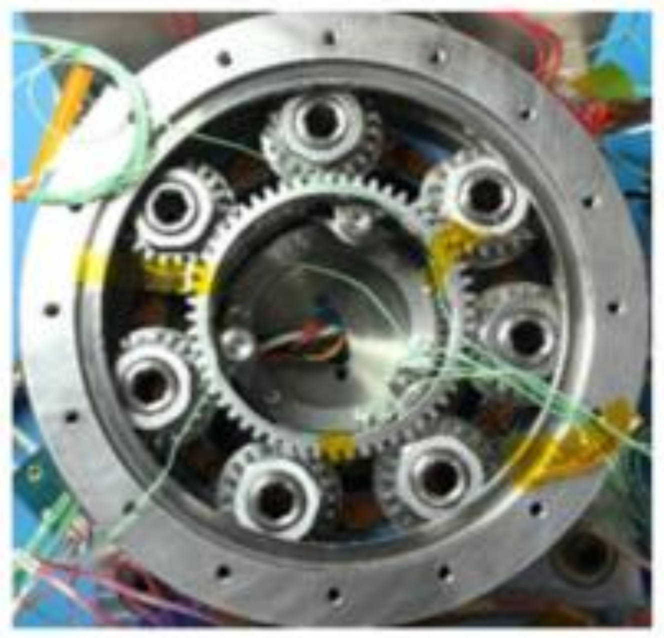


Actuator 2ϕ parts fabricated (PBF)

TRL4

Actuator parts performance validation in lab environmnet

FY21



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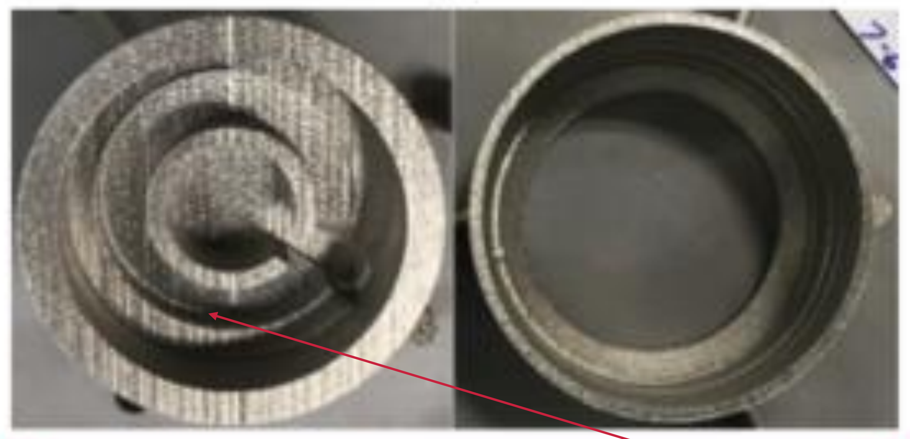
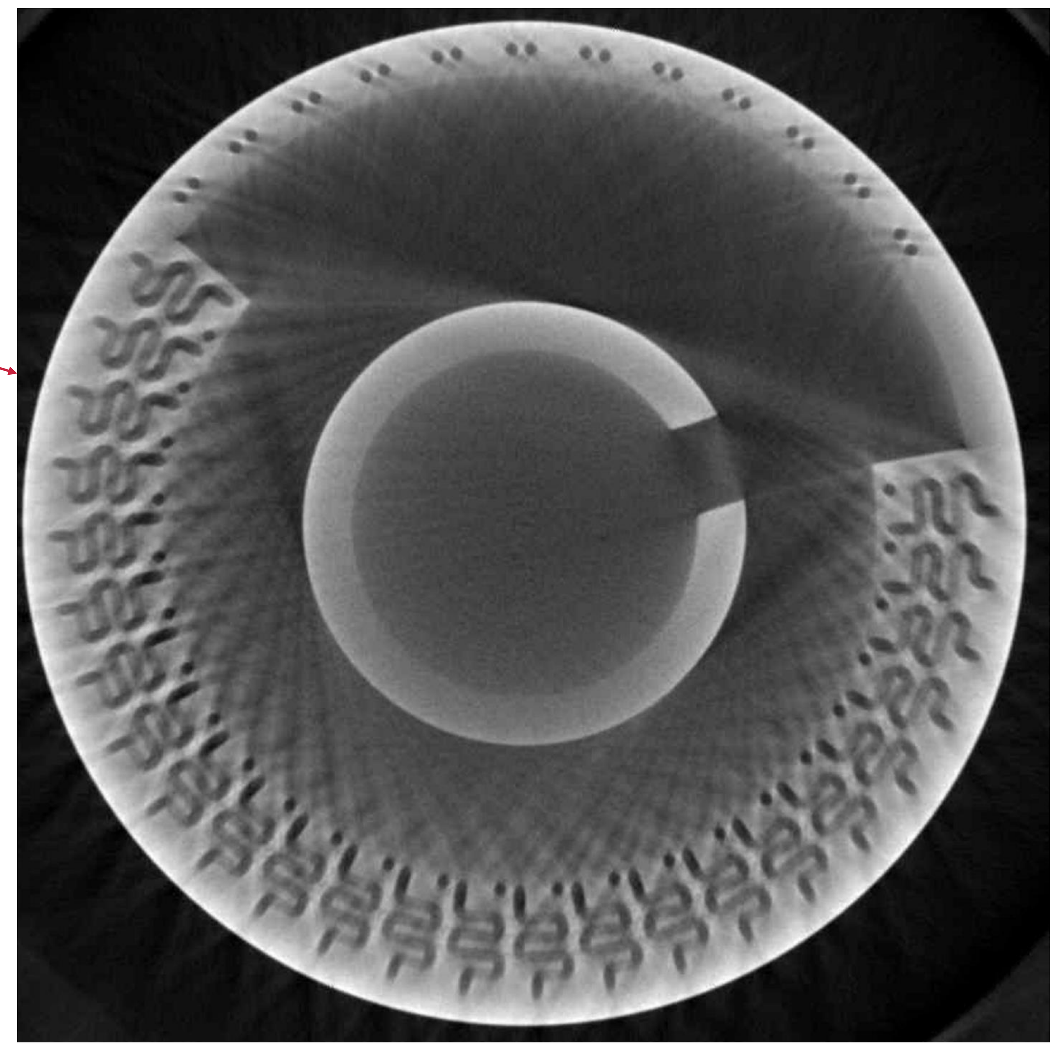


Characterization Testing and Thermal Vacuum Test of Full Actuator Prototype (Electric Motor and Gearbox) And Extended Life Testing of full actuator prototype **TRL5/6**

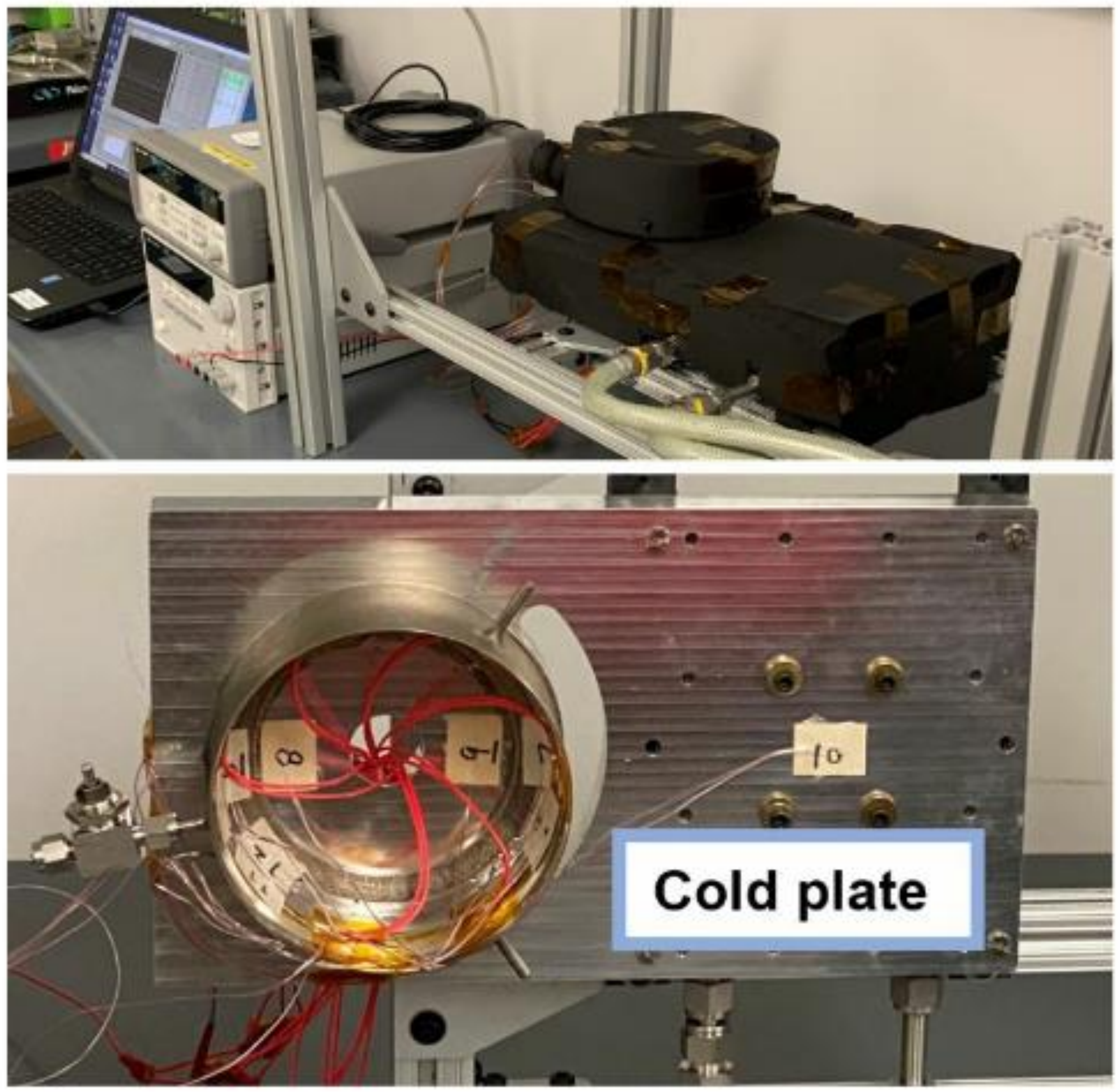
Innovation, advancement

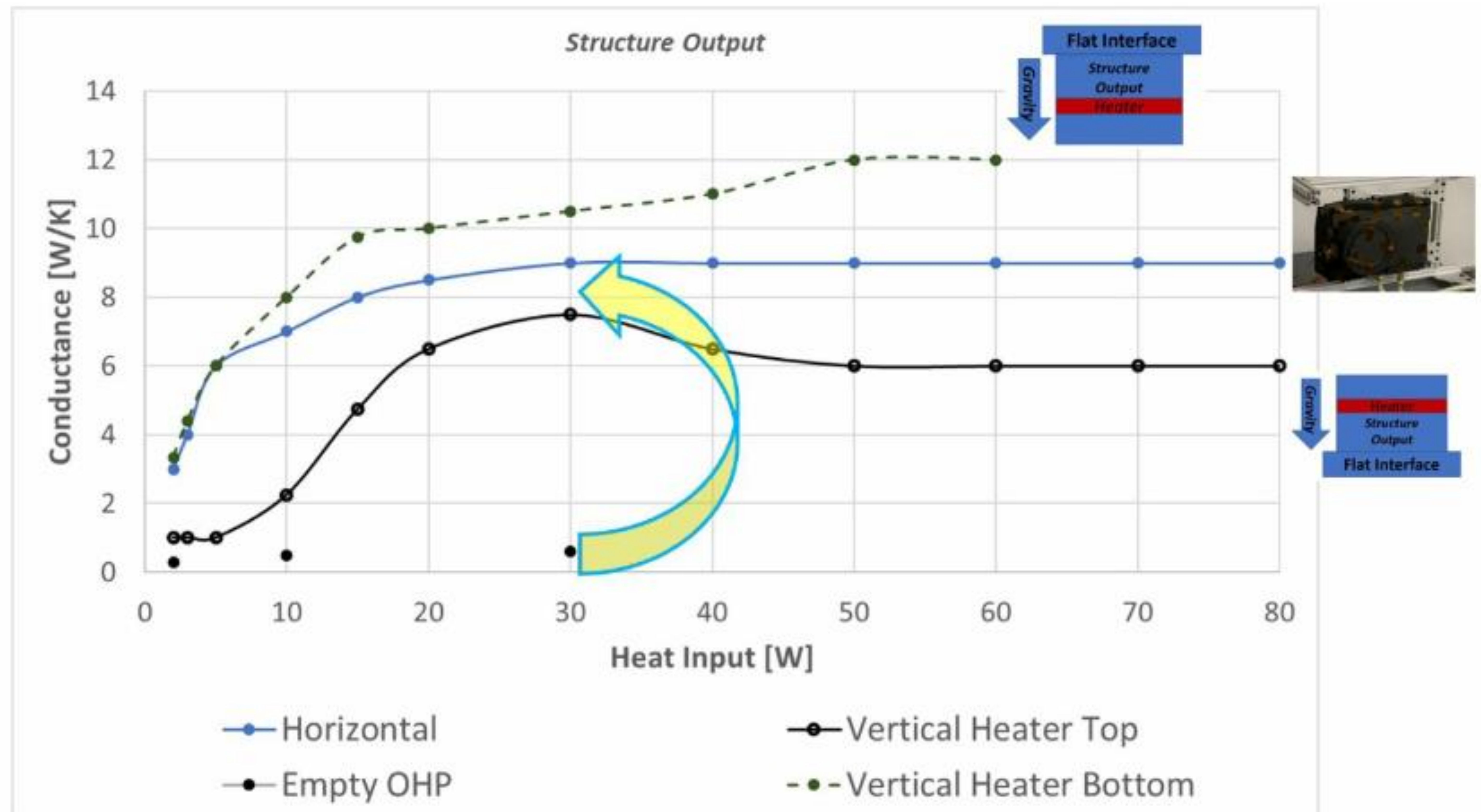
- Use additive manufacturing techniques (PBF) to efficiently bridge the heat source (electric motor) to the heat sink (gearbox/housing) with 2ϕ OHP (Oscillating Heat Pipe)
- 100x improvement in thermal conductance over base material (Inconel)
- Thermal enhancement led to 10x improvement in power density



Approach and Results (2/5)

Structure Output Subassembly Level Test



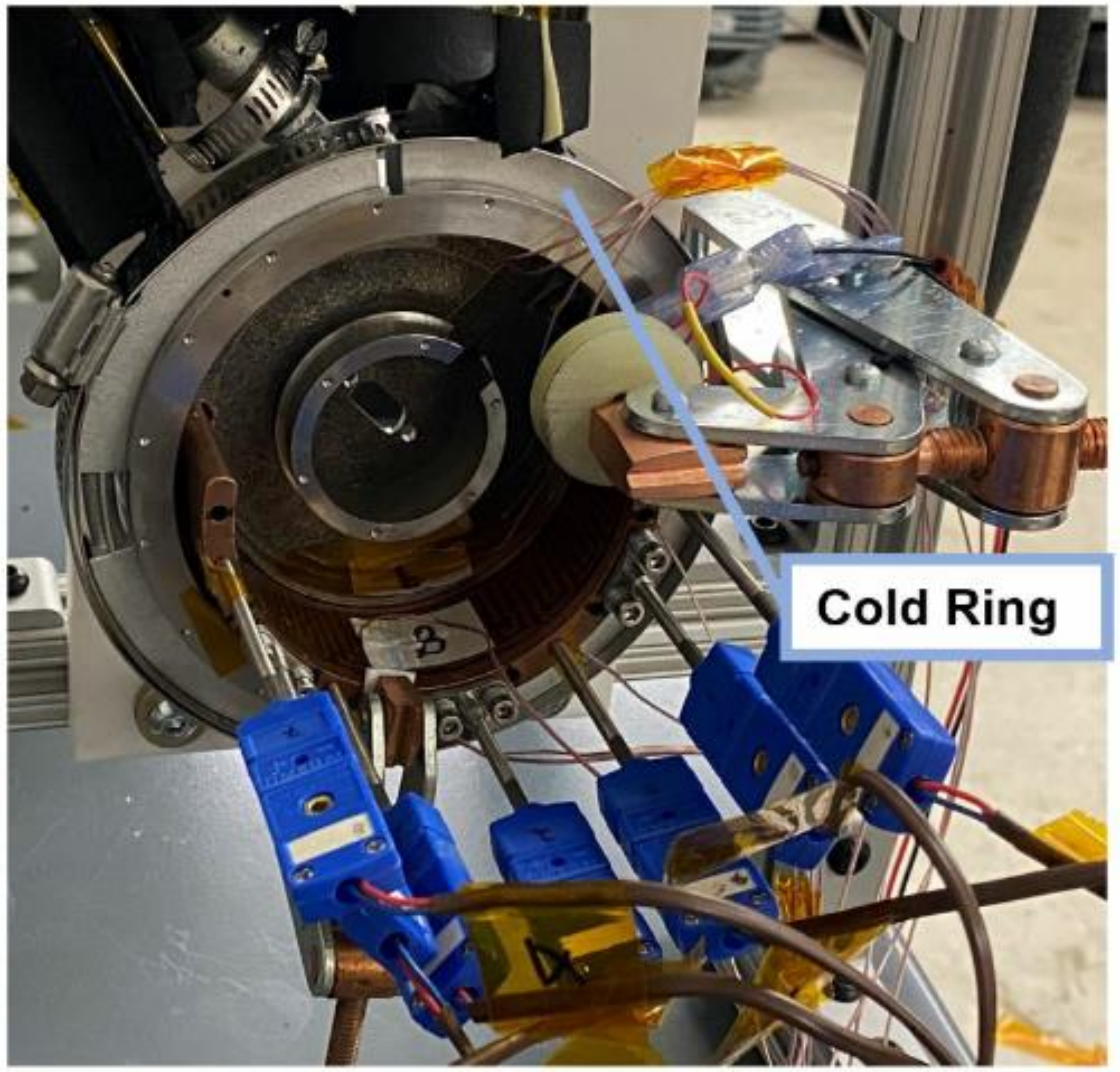


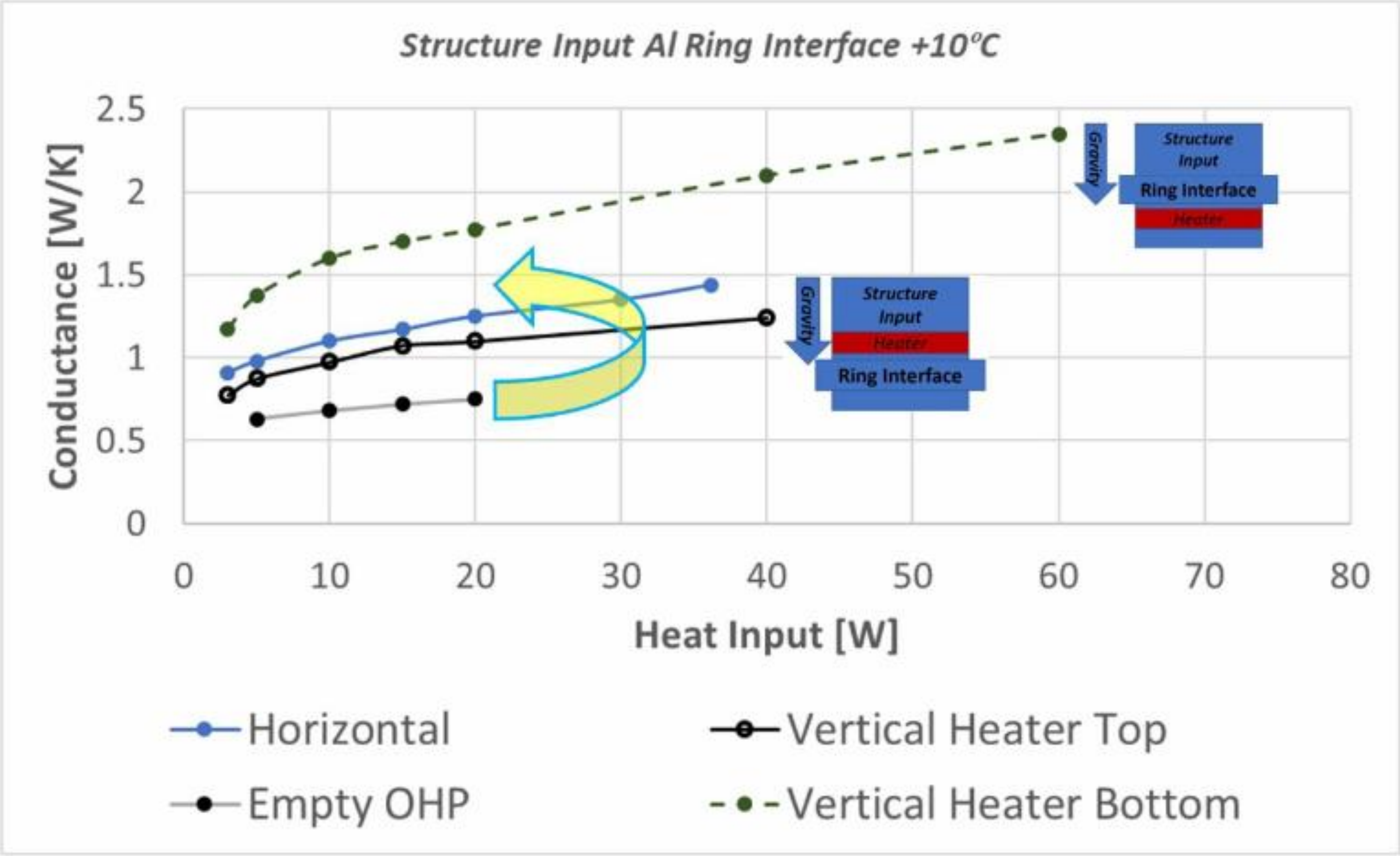
- **Working fluid**: R134a
- **Fill ratio**: 50% @ 27°C

Preliminary results show that 3D printed output structure with 2ϕ OHP improves the thermal conductance by a factor of up to 20 depending on the hardware orientation.

Approach and Results (3/5)

Structure Input Subassembly Level Test
Ring Interface



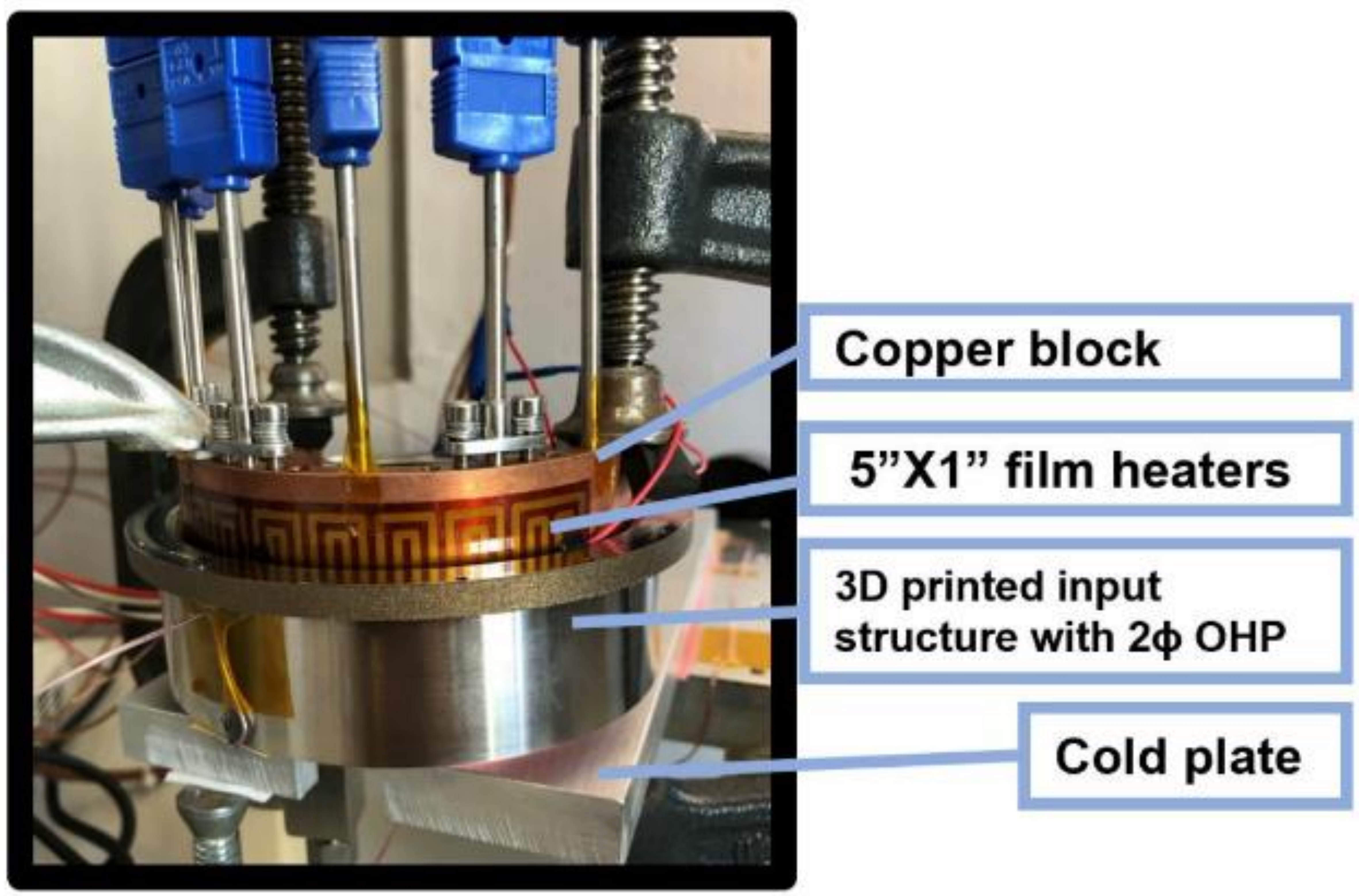


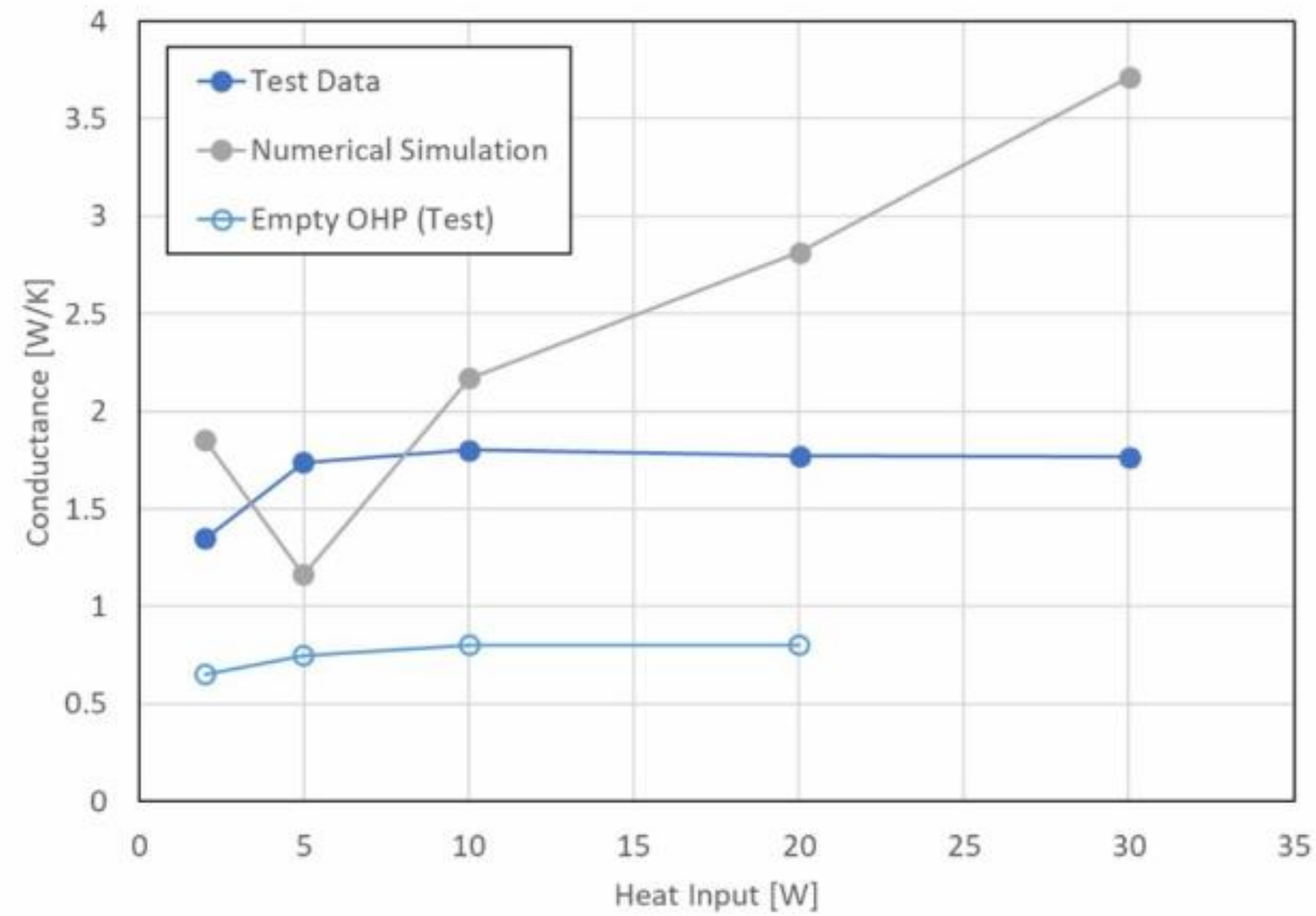
- **Working fluid**: R134a
- **Fill ratio**: 51% @ 18.5°C
- **OHP volume**: 6.09 mL
- **Dead space volume (ports + valve)**: 0.11 mL
- **CAD based OHP volume**: 7.27 mL

Results show that 3D printed input structure with 2ϕ OHP improves the thermal conductance by a factor of up to 2.4 depending on the hardware orientation.

Approach and Results (4/5)

Structure Input Subassembly Level Test Flat Interface





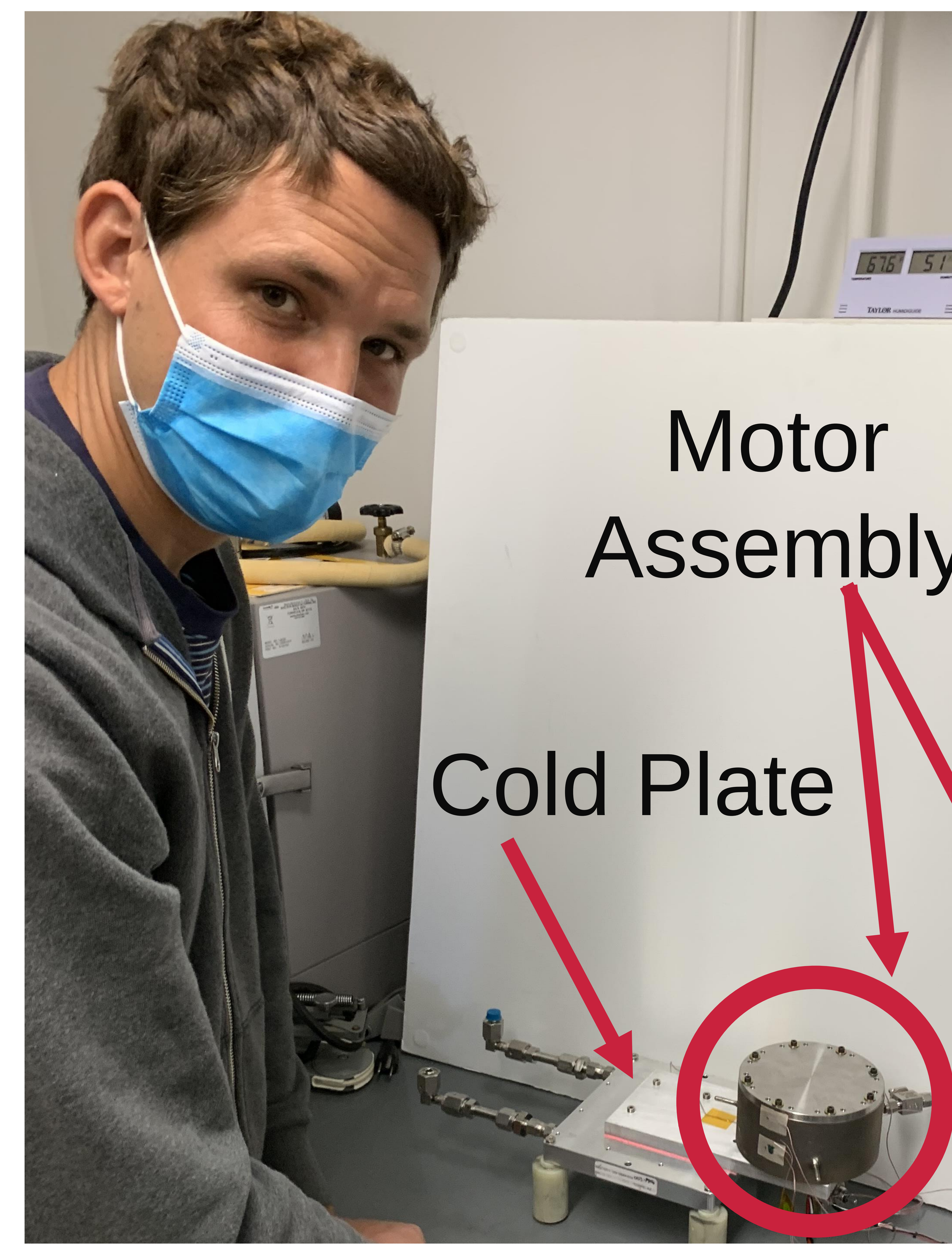
- **Working fluid**: R134a
- **Fill ratio**: 51% @ 18.5°C
- **OHP volume**: 6.09 mL
- **Dead space volume (ports + valve)**: 0.11 mL
- **CAD based OHP volume**: 7.27 mL

Results show that 3D printed input structure with 2ϕ OHP improves the thermal conductance by a factor of 2.25. Additional tests with different hardware orientation are in progress.

Approach and Results (5/5)

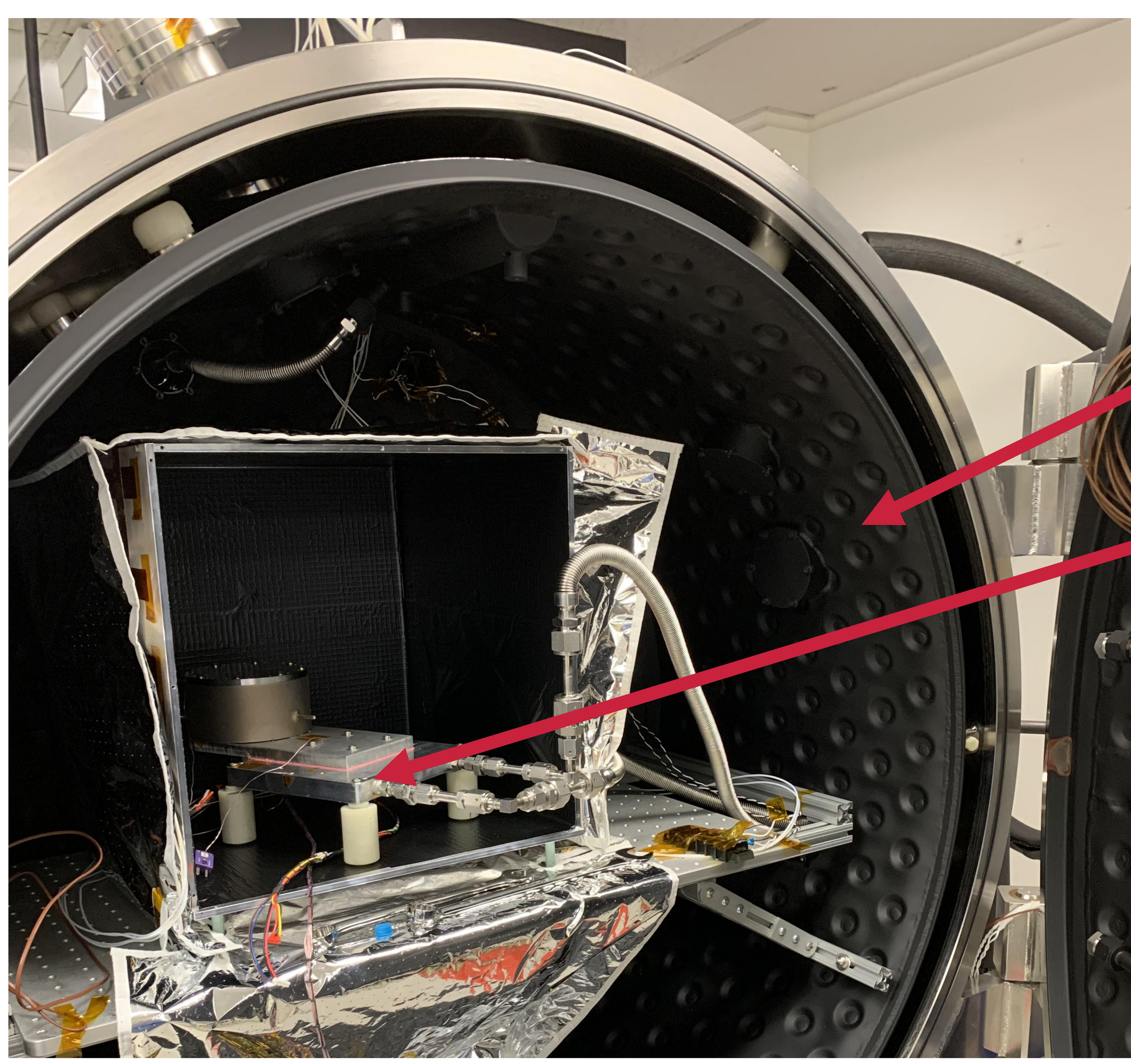
Actuator Assembly

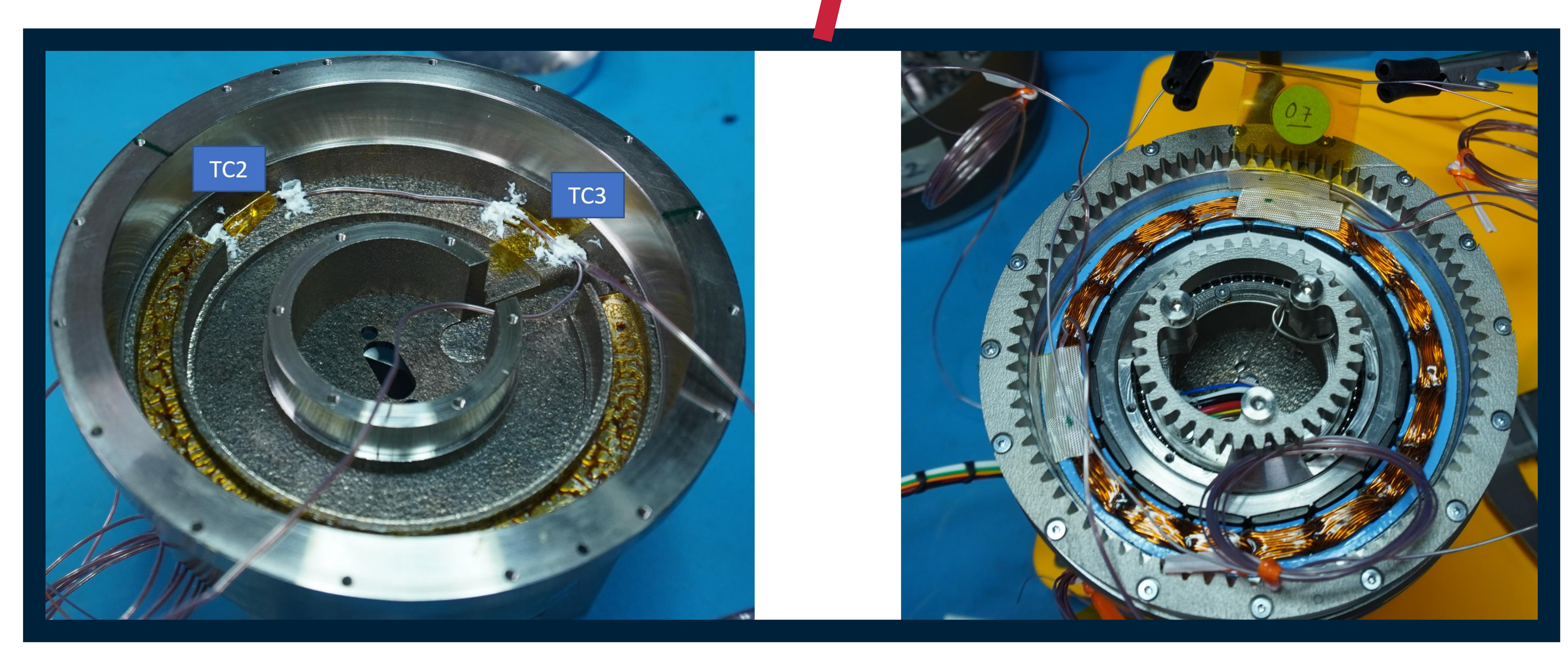
- 3D Printed parts were integrated with the full motor assembly
- A TVAC test completed on the full assembly actuator
- Collected data does show a thermal improvement from empty to filled OHP
- Team is repeating the test with better instrumentation to capture the OHP performance



Ben Furst – Thermal Co-I

Jay Jasper– Robotics Co-I





Significance and Benefits to JPL and NASA

a) **Context (Why this problem and why now):** Thermal management of actuators has been a problem for every flight mission. For example, MSL's robotic arm actuators are typically not operated until noon, needing to take full advantage of ambient Martian conditions to passively pre-heat the lubrication within an actuator's gearbox. A new and more direct engineered thermal path from within the electric motor (which generates heat and requires cooling) to the gearbox (where lubrication must be pre-heated) is needed to create a significant improvement to both the thermal and temporal efficiency of JPL's flight actuators specifically to ***time limited and power limited missions such as Europa Lander.***

b) **Relevance to NASA and JPL (Impact on current or future programs):** Short duration Ocean worlds cannot rely upon environmental heating for their actuators. By harvesting waste heat from the electric motor to thermally condition the gearbox, missions such as Europa Lander can perform more science in less time with less power. For this technology the following category of missions are enabled: 1. Time limited missions requiring rapid sampling (Europa Lander) 2. Power limited missions (Icy moons) 3. Missions require high power density (Helicopters, swimmers, and melt probes)

Reference and Publications

Publications:

[1] Elham Maghsoudi, Ben Furst, Jay D. Jasper, Takuro Daimaru, and Kimihide Odagiri, “Efficient Thermal Management for Sampling Arm Actuators,” Published in Proceeding of 2020 International Conference on environmental Systems (ICES).

[2] Emma Nelson, Elham Maghsoudi, Jay D. Jasper, and Thomas Peev, “Thermal Characterization of an In-runner Double Row Planetary Actuator,” Submitted to 2020 Aerospace Thermal Control Workshop,Torrance, CA, March 2020.

References:

[1] Wrist and Turret et RSM Actuator Mars Science Laboratory Detail Specification, JPL D-37255 Rev C, MSL 576-1577,August 2008

[2] Nikola Georgiev and Joel Burdick, “Design and Analysis of the Bearingless Planetary Gearbox,” 2017 IEEE/RSJInternational Conference on Intelligent Robots and Systems (IROS), September 24-28, 2017, Vancouver, BC, Canada.

[3] Takuro Daimaru, Shuhei Yoshida, amd Hiroki Nagai, “Study on thermal cycle in oscillating heat pipes by numerical analysis,” Applied Thermal Engineering,Vol. 113, 2017, pp. 1219-1227.

[4] Takuro Daimaru, Hiroki Nagai, Makiko Ando, Kosuke Tanaka, Atsushi Okamoto, and Hiroyuki Sugita, “Comparison between Numerical Simulation and On-orbit Experiment of Oscillating Heat Pipes,” International Journal of Heat and Mass Transfer, Vol.109, 2017, pp.791-806.