TFAWS Active Thermal Paper Session

Development of a 3D Printed Loop Heat Pipe

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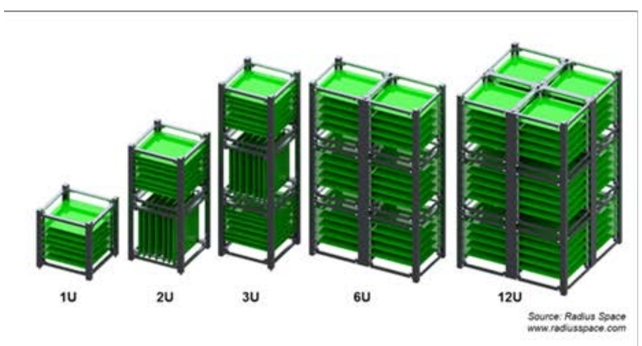
Outline

- Background
- DMLS Primary Wick Fabrication
- Prototype Test Results
- DMLS Bi-porous/ Graded Wick
- Summary

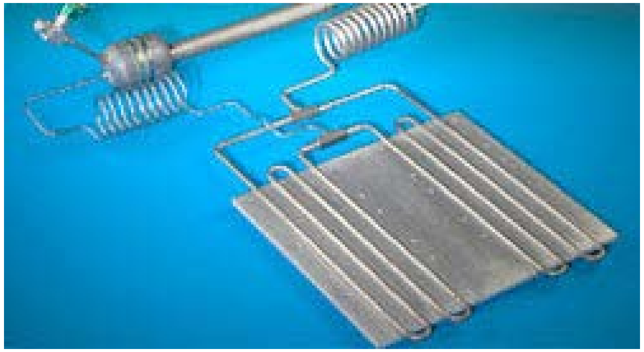
Background

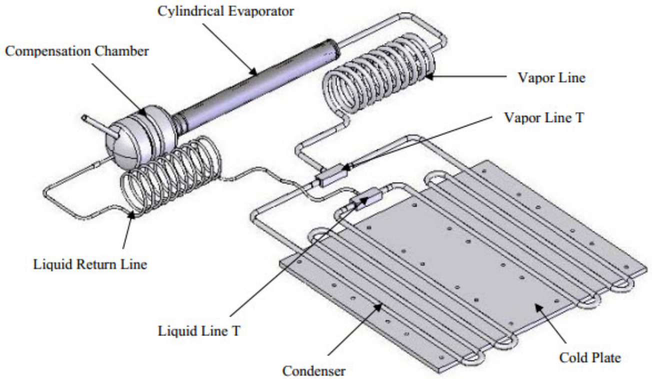
- CubeSats (10 cm x 10 cm x 10 cm units) and SmallSats are becoming increasingly popular due to their lower development times and costs
- Advances and miniaturization of electronics has increased the capabilities of the CubeSat platform, and therefore heat dissipation requirement
- Low cost, deployable thermal management system is desired



Loop Heat Pipe

- Loop Heat Pipe (LHP) is a passive device that transfer heat along a loop via two phase flow
- The vapor and liquid line are simple tubes (no wicks) make it feasible to connect with a deployable radiator
- Currently LHPs are very costly to manufacture
  - > $25,000 for standard LHPs, > $100,000 for custom LHPs
  - Will take up a significant fraction of the total CubeSat cost

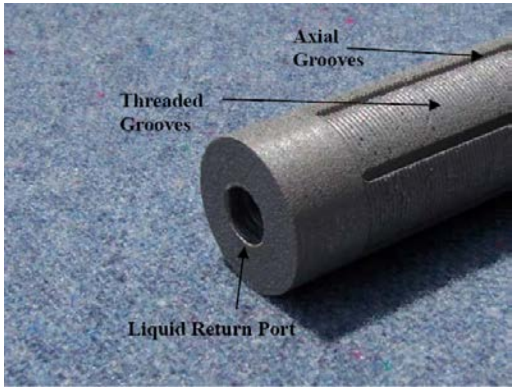


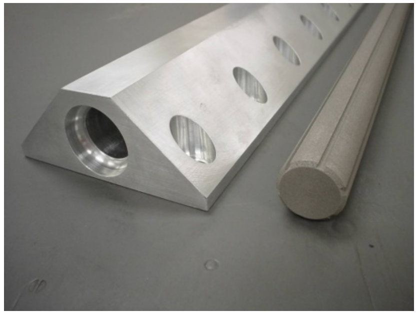


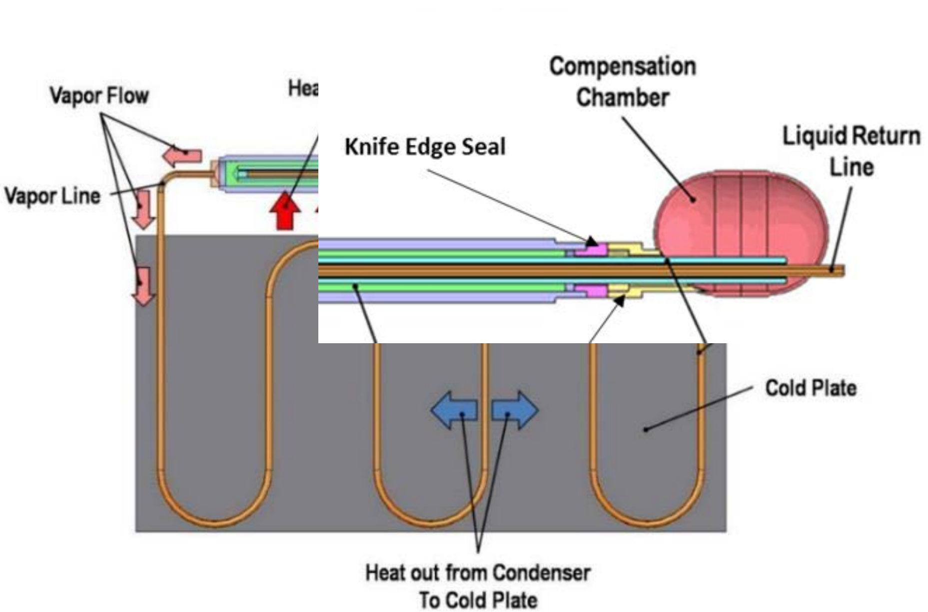
Current LHP Evaporator Fabrication

- Require multiple steps and very skillful labors

1. Sinter wick
2. Machine vapor grooves
3. Insert wick to the evaporator envelope
4. Knife edge seal to prevent backflow of vapor from primary wick to compensation chamber (very troublesome)

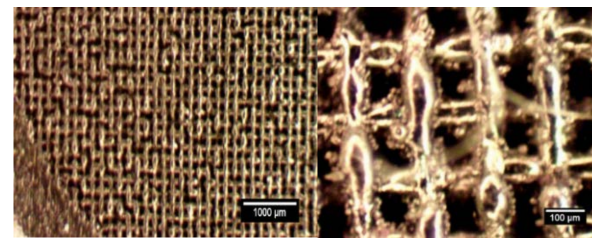


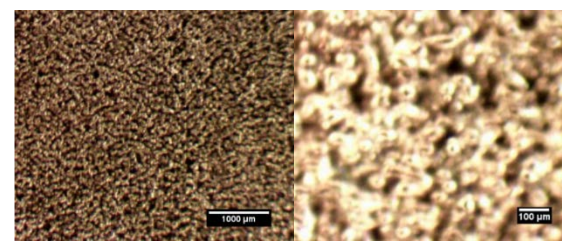


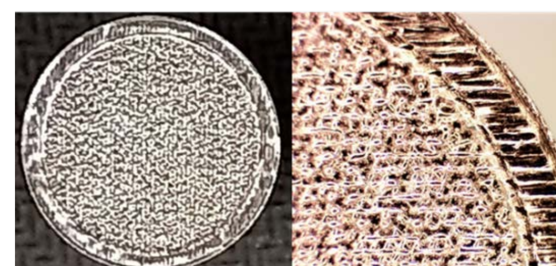


DMLS Wick Fabrication

- Direct Metal Laser Sintering (DMLS) is a process by which metal structures are made in a layer-by-layer sintering process
  - Able to make a complicated component in a single part to avoid joint/ seal challenges
- Several different DMLS techniques can be used to create porous wick structures
  - Lattice Structure
  - Increased laser spacing compared to fully dense parts
  - Reduced power to prevent fully melting powder
- Wick can be fabricated simultaneously with a fully dense envelope
  - Vapor grooves do not need to be machined
  - Eliminates the need for a knife-edge seal
  - Eliminates wick insertion step



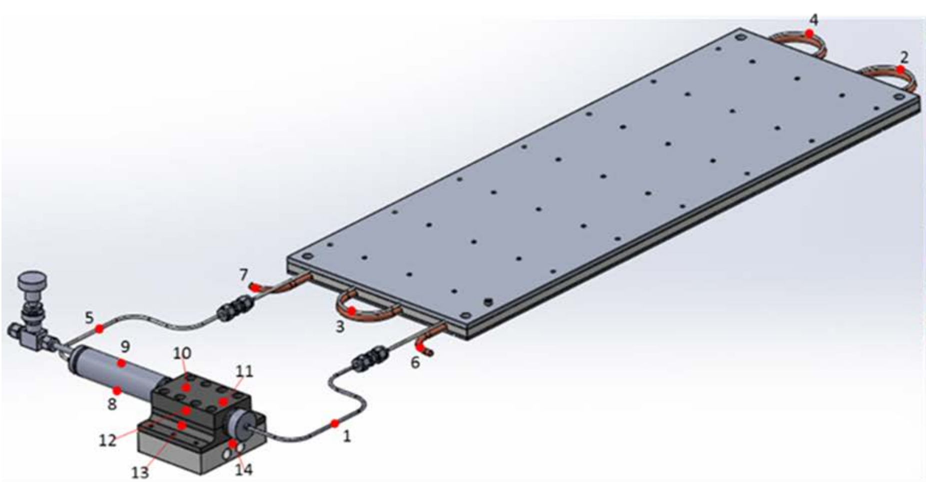




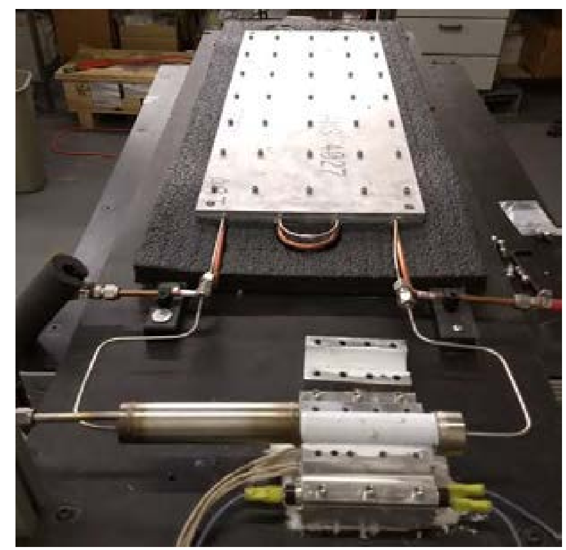
Prototype Setup

- **Prototype Design**
  - Wetted Material: 316L SS
  - Working Fluid: Ammonia
  - Tubing: 3.18 mm OD
  - Condenser Length: 3.2 m
  - Primary Wick
    - Pore Radius: 6 µm
    - Permeability: 6.7×10^{-14} m^2
  - Evaporator
    - Length: 100 mm
    - Diameter: 25 mm

- **Test Conditions**
  - **Sink Temperature: 0°C**
  - **Adverse Elevation: 12 mm**
  - **Steady State Test**
    - **Power Increased in 5 W increments**
    - **Used to determine maximum power**
  - **Low Power Startup**
    - **Power set to 5 W**
    - **Used to verify low heat leak**

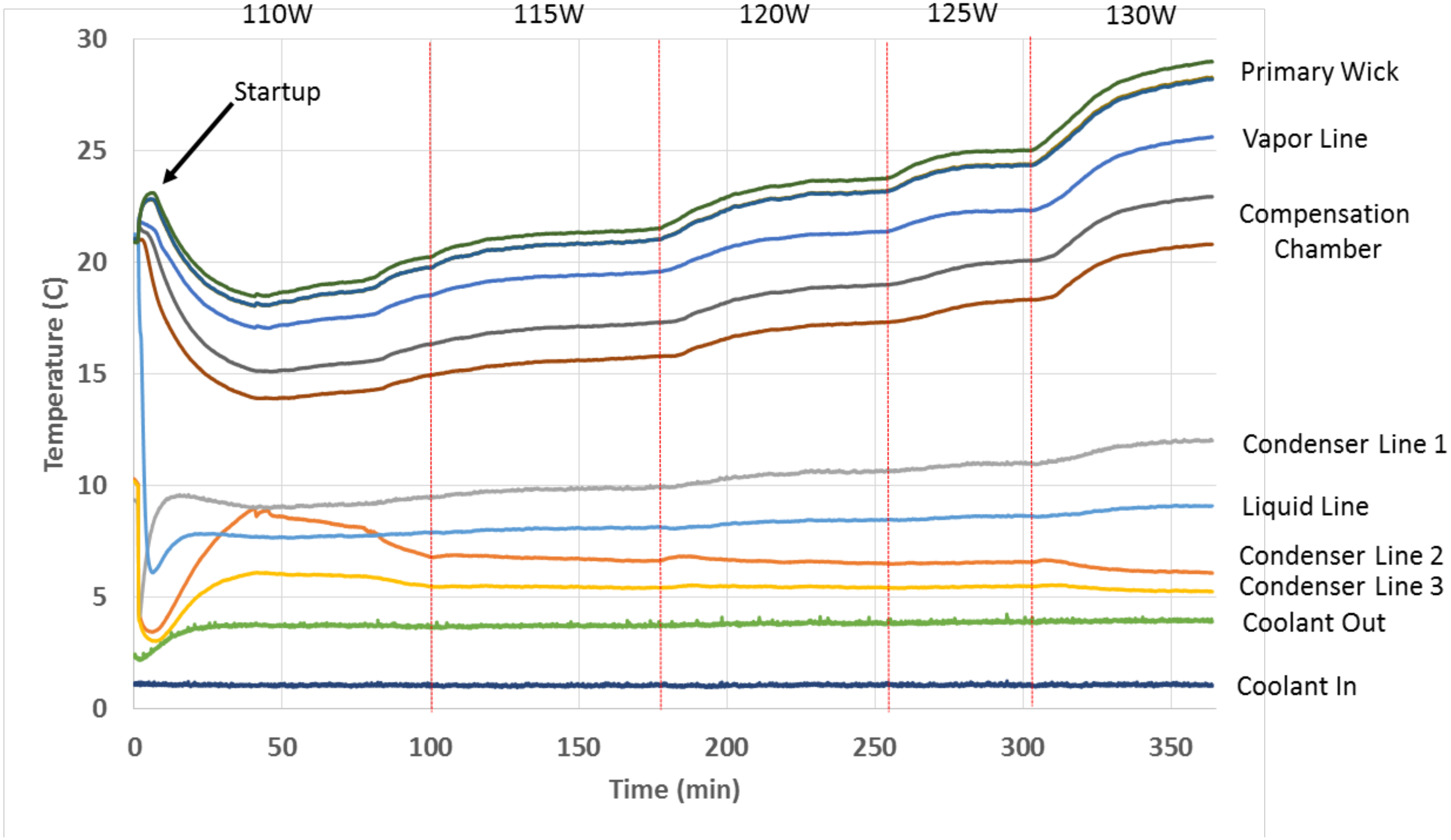


TC	Location
1	Vapor Line
2	Condenser Line
3	Condenser Line
4	Condenser Line
5	Liquid Line
6	Coolant In
7	Coolant Out
8	Compensation Chamber
9	Compensation Chamber
10	Primary Wick
11	Primary Wick
12	Al Saddle Top
13	Al Saddle Bottom
14	Heater Block



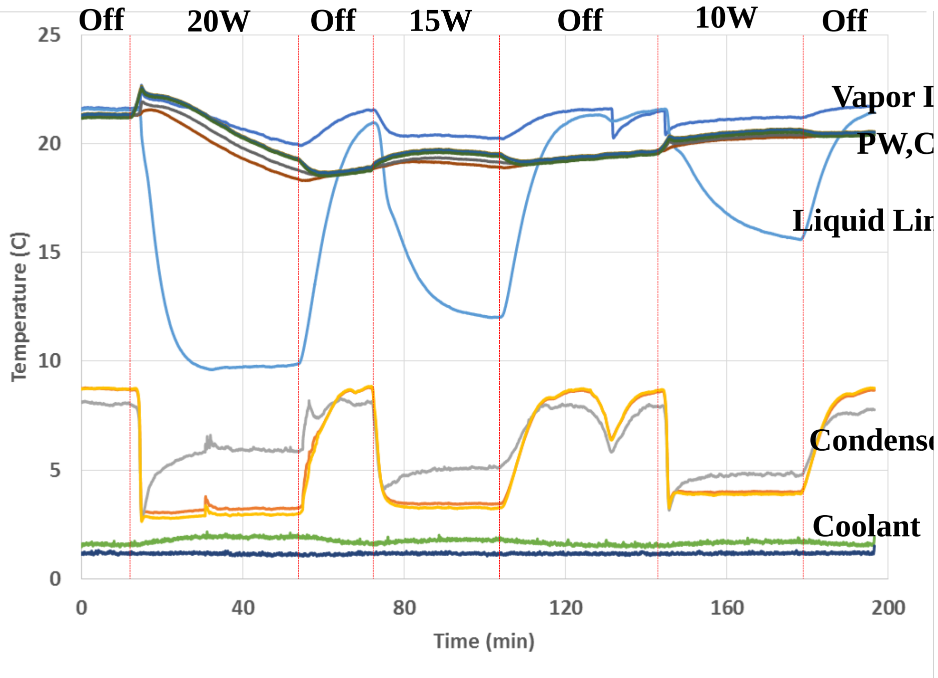
Thermal Test

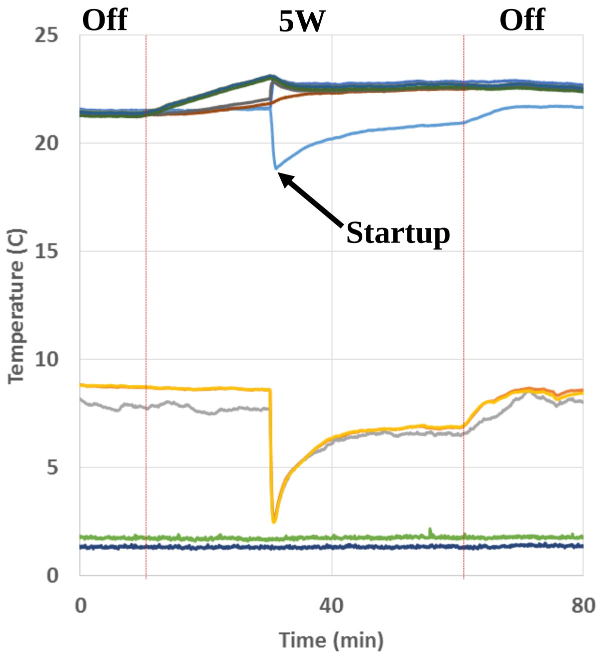
- Maximum power of 125 W before dry-out



Startup Performance

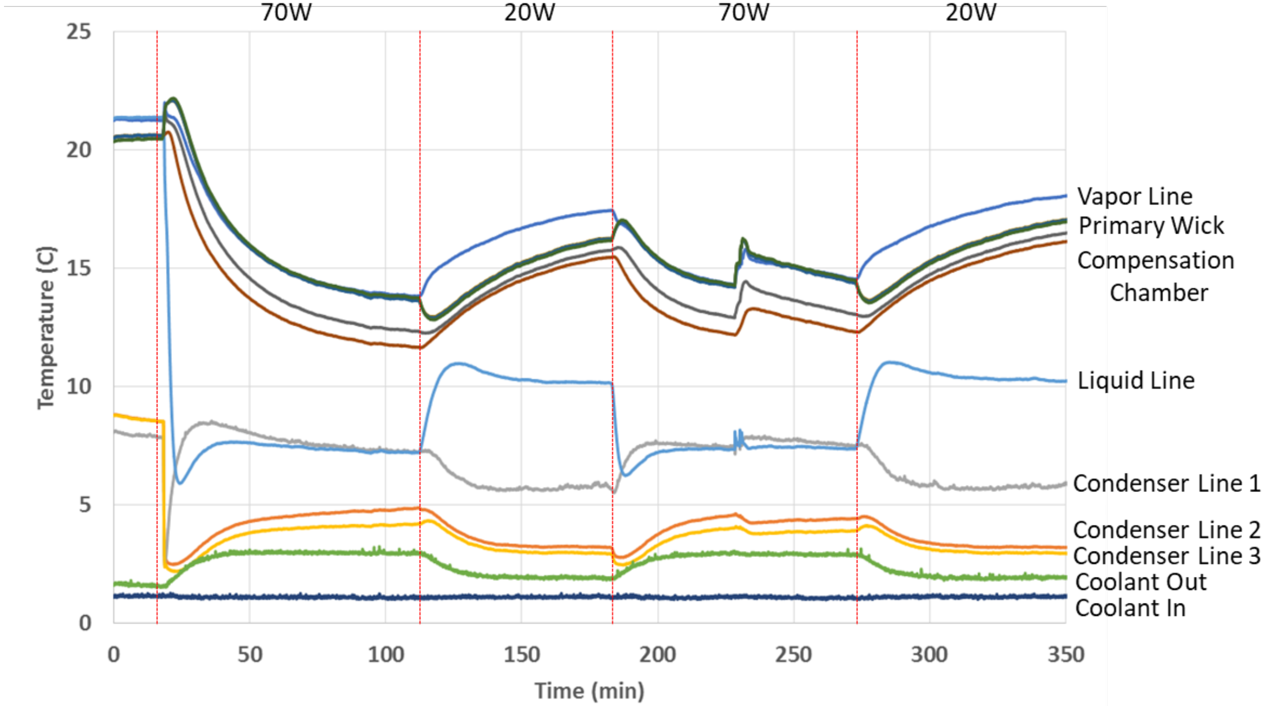
- Startup was immediate at heat loads of ≥ 10 W
- Successful startup at power as low as 5 W
  - Indicates that there is not a significant amount of heat leak
    - Large enough pressure difference between evaporator and compensation chamber



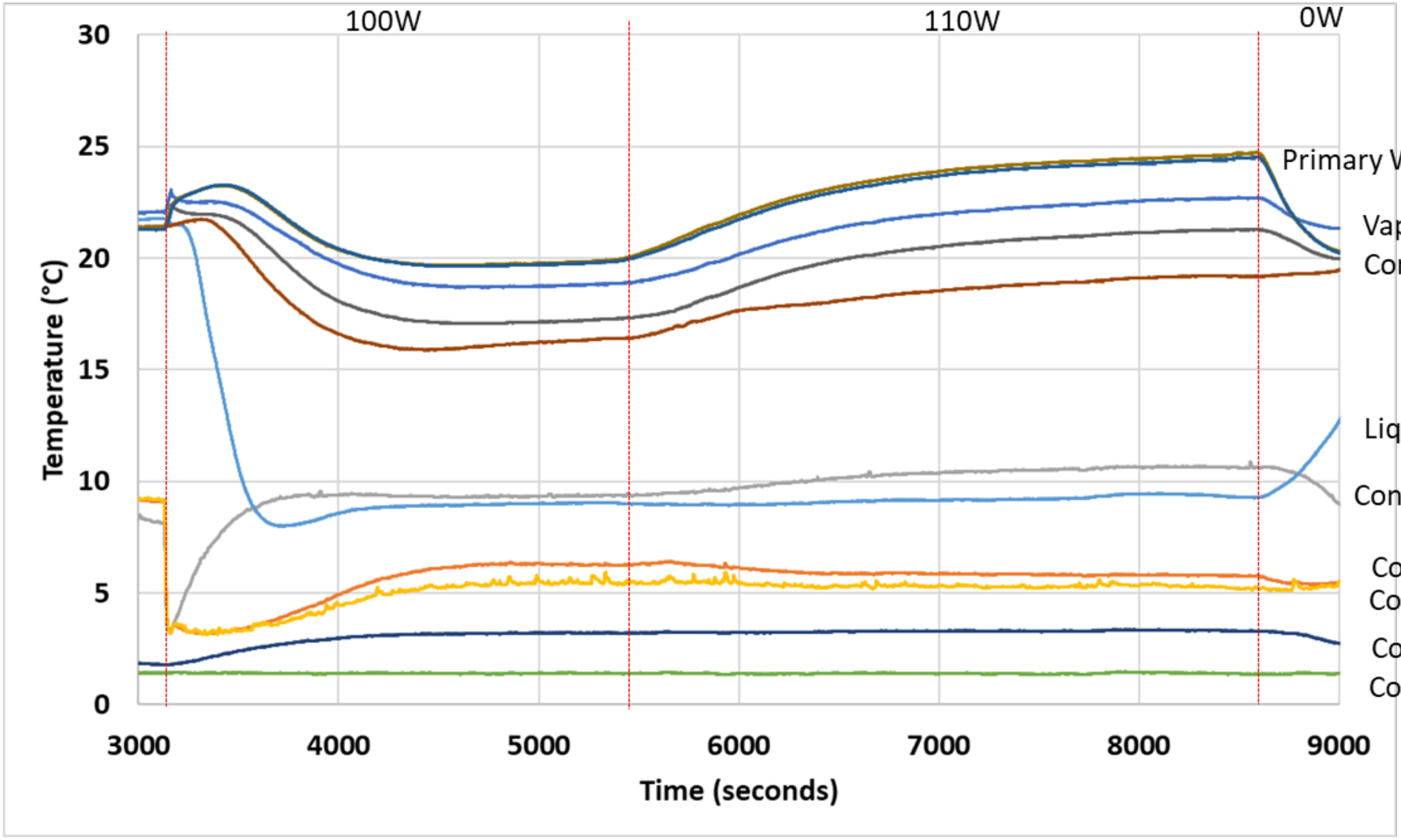


Thermal Cycling

- Dry-out did not occur during rapid changing of heat load between 20W and 70W
  - Verifies ability of secondary wick to handle transients

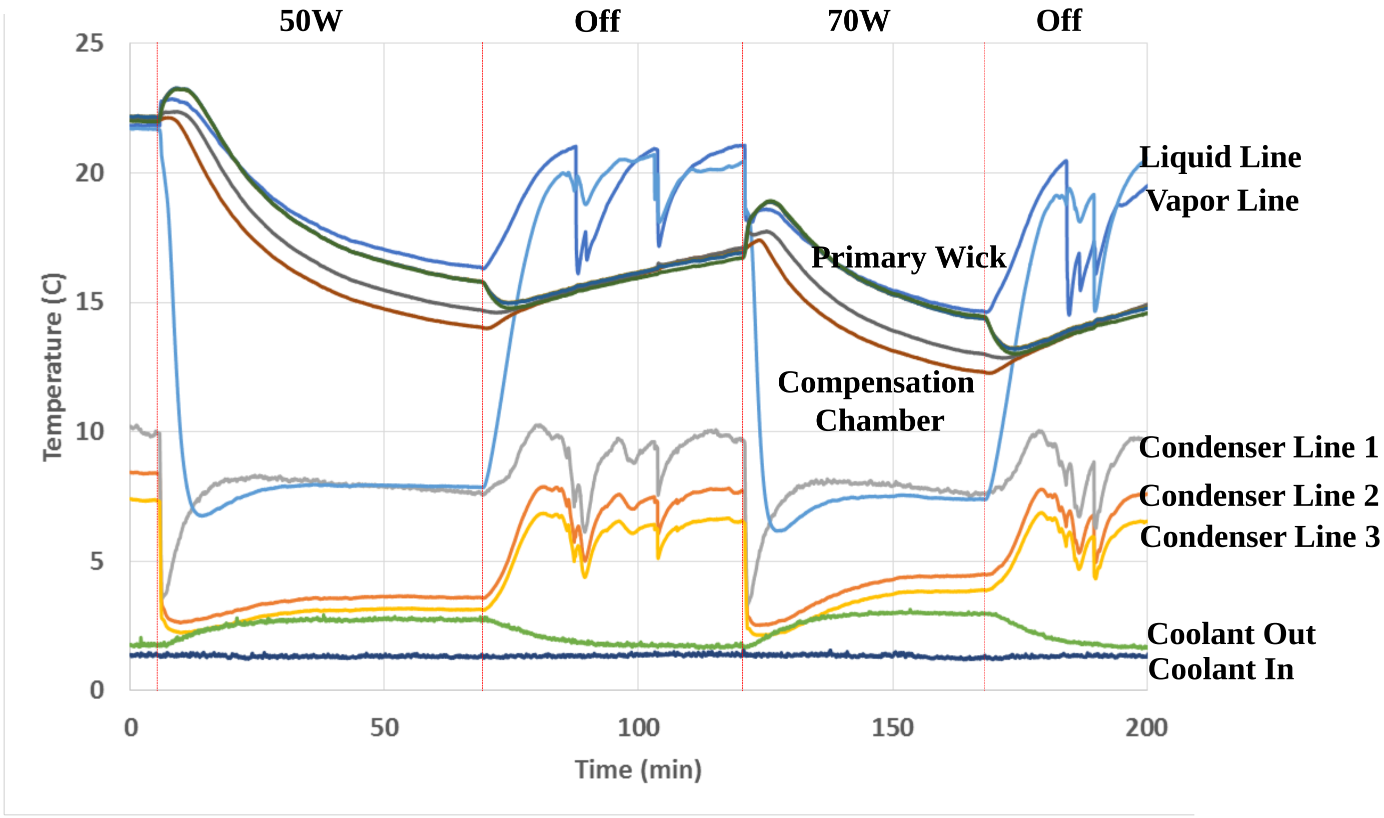


- Evaporator raised 5.25" above condenser
- Reached steady state at 110 W



Against Gravity

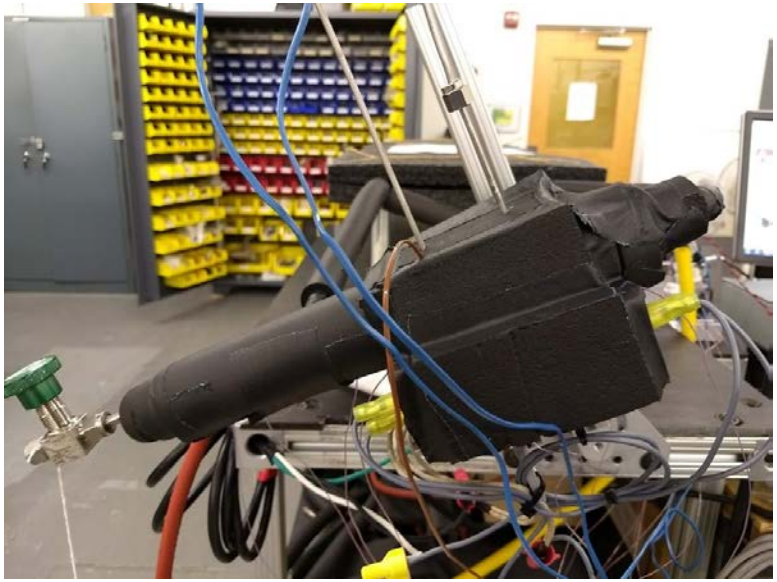
- LHP tilted so evaporator was 6” above lowest point of condenser
  - Operated normally at 50W and 70W



Flexible Vapor and Liquid Lines

- Flexible lines added between evaporator and condenser
  - Can test against gravity while keeping both condenser and evaporator parallel with the ground
  - Can test angled evaporator for rover based applications

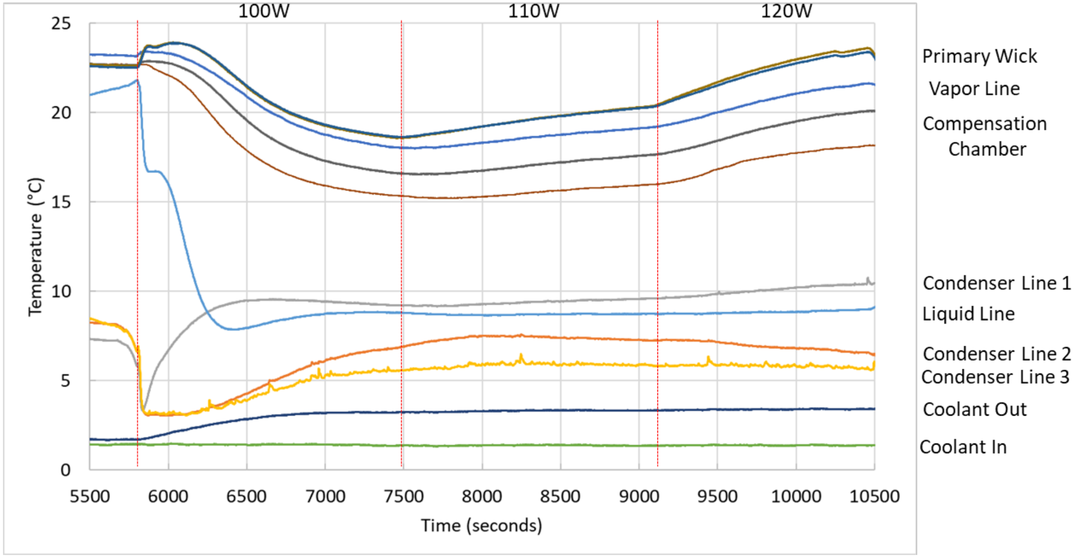
LHP with flex lines



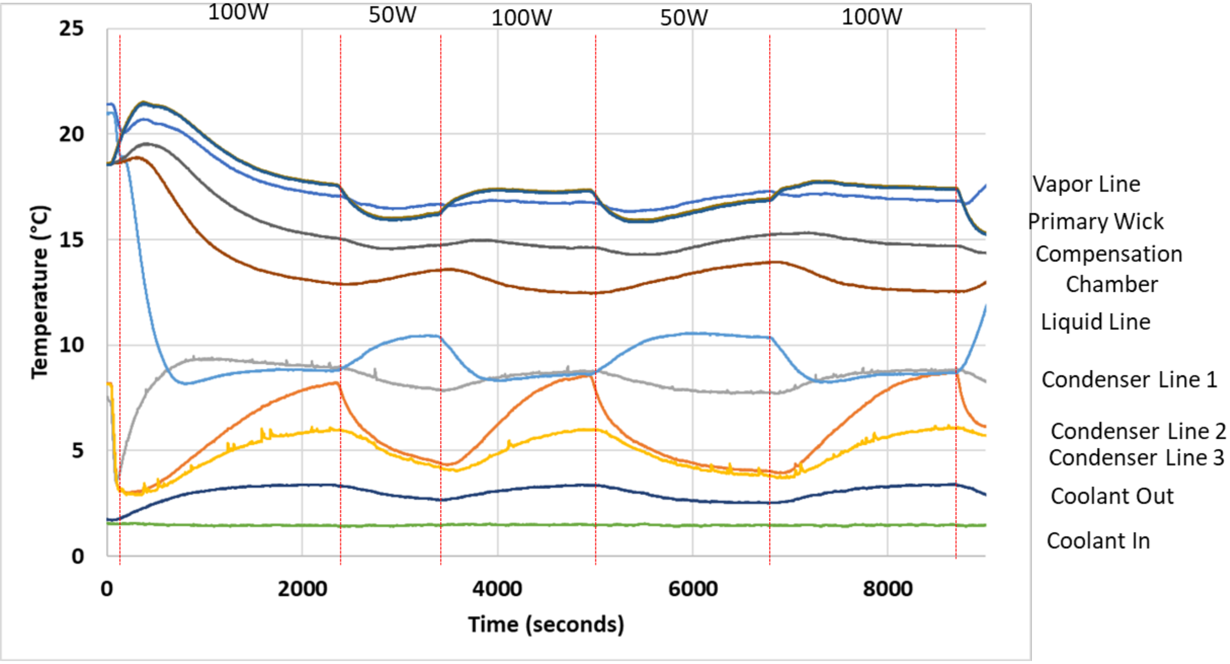
LHP evaporator angled at 25°

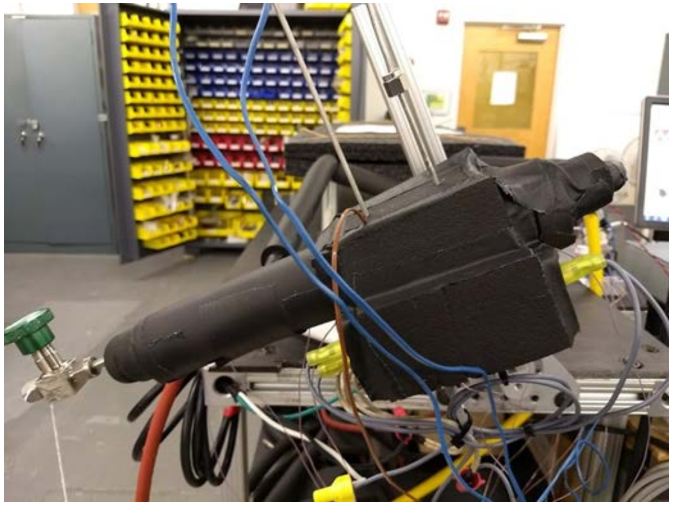
Flexible Vapor and Liquid Lines

- Baseline test without adverse conditions
- Reached steady state at 100 and 110W
- Overtemp controller kicked on at 120W
  - Previously reached 125W without flex lines
  - Flex lines add pressure drop to the system and also may increase heat leak from the environment



- Evaporator tilted at 25º
  - Secondary wick working against gravity
- Successfully operated through power cycles between 100W and 50 W



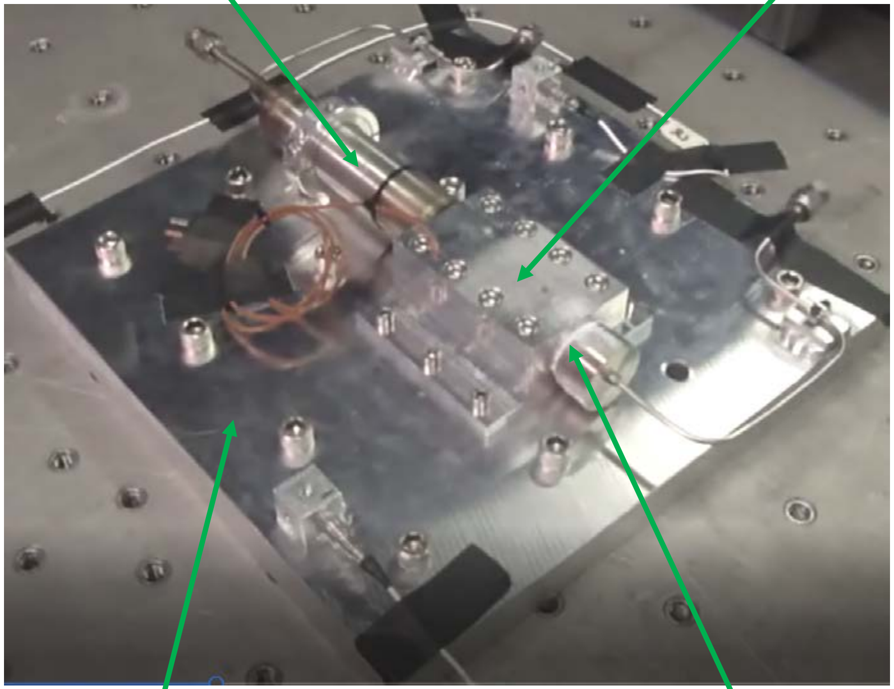


Vibration Loading

- Goal is to demonstrate robustness of 3D printed wick

Random Vibration Spectrum – X and Y Axis	
Frequency (Hz)	g^2/Hz
20	0.020
50	0.080
800	0.080
2000	0.020

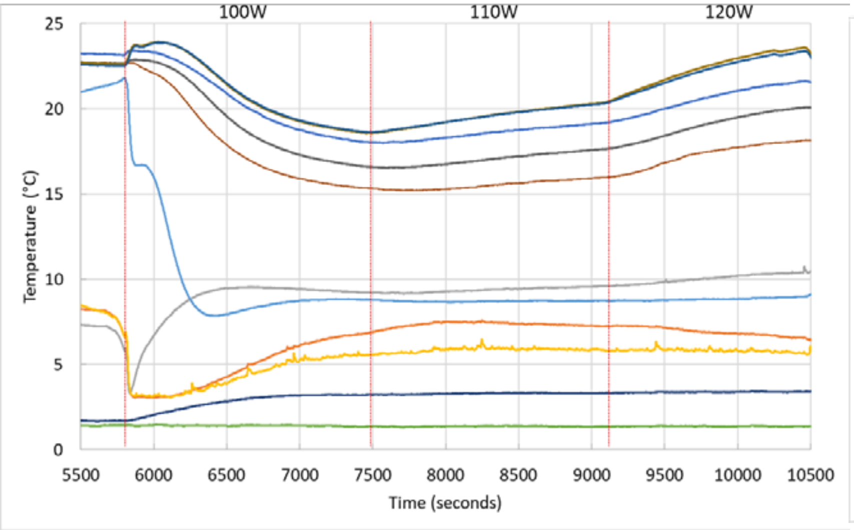
Random Vibration Spectrum – Z Axis	
Frequency (Hz)	g^2/Hz
20	0.026
50	0.160
800	0.160
2000	0.026



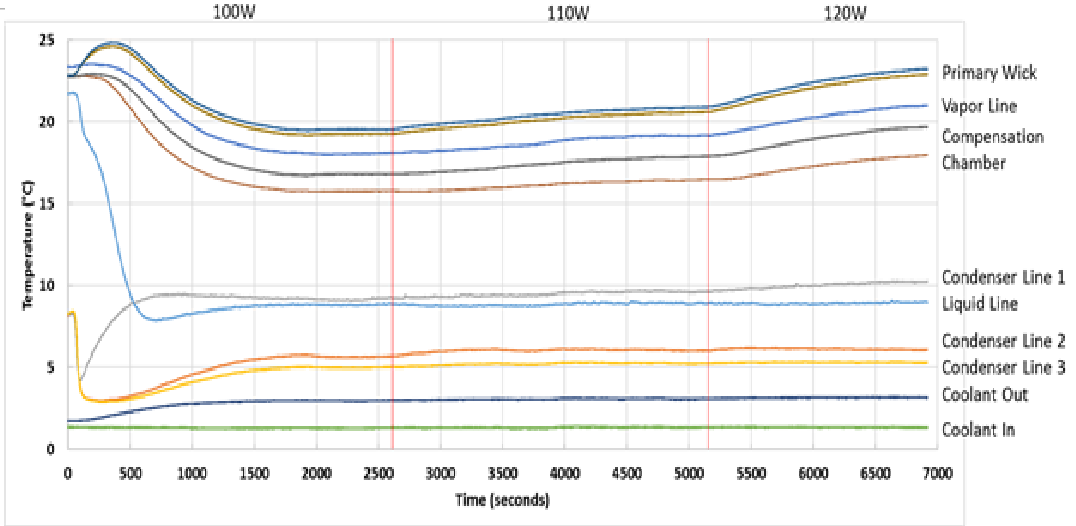
Vibration Loading

- LHP prototype test results before and after vibration loading with flexible lines installed
  - Successfully started and operated after vibration loading, indicating no significant damage was sustained

Before Vibration Loading

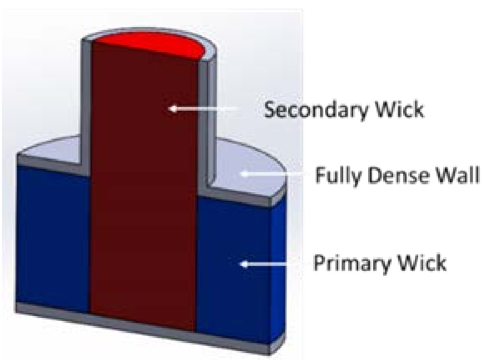


After Vibration Loading

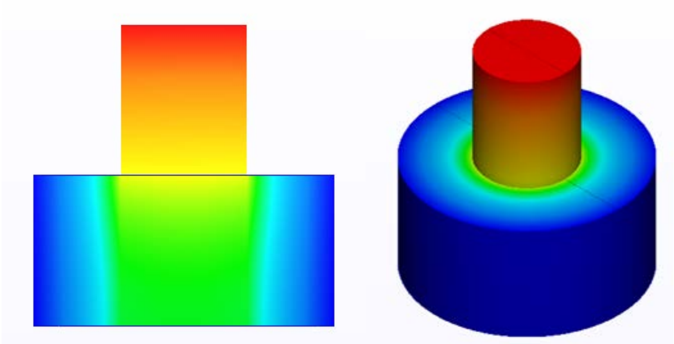


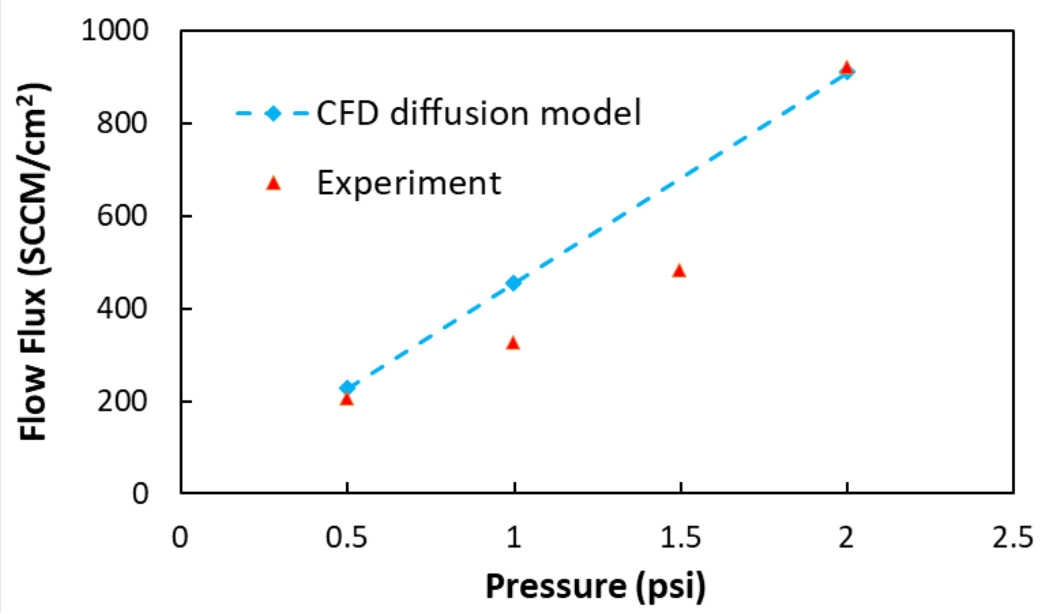
Bi-Porous/ Graded Wick

- A 3D printing sample shows that bi-porous wick (5 um and 30 um) can be printed together with fully dense wall
- This allows printing primary and secondary wick together



- The initial flow test shows good match with CFD based model (via thermal and fluid analogy)

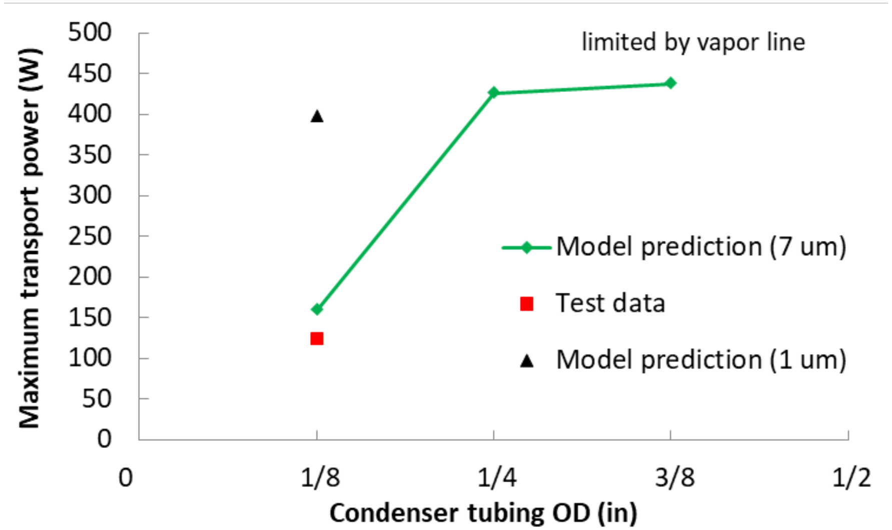




Power Limitation

- The current design has 1/8" condenser tubing, which contribute dominant pressure drop (6,986 Pa at 150 W input)
- The 3D printed primary wick only create 126 Pa at 150 W input
- Increase condenser tubing size to 1/4" can **increase the power limit to > 400 W** for the same 3D printed primary wick
  - Increase vapor line diameter will further increase the maximum power limitation (> 2,000 W, without considering heat leak)

ΔP at 150 W input	Value	Unit
ΔP Vapor Line	1358.31	Pa
ΔP Condenser	**6985.98**	**Pa**
ΔP Condenser (minor losses)	1769.51	Pa
ΔP Liquid Line	55.38	Pa
ΔP Wick (Axial)	0	Pa
ΔP Wick (Radial)	**125.5**	**Pa**
ΔP Axial Grooves	2.08	Pa
ΔP Flex Connection	3065.25	Pa
ΔP Gravity	79.75	Pa
Total ΔP	8607.03	Pa
Maximum Available ΔP	**9514.57**	**Pa**
ΔP Margin	907.542	Pa



Summary

- A LHP with a 3D printed (DMLS) evaporator (4” long) has demonstrated up to 125 W thermal power transport
- The 3D printed evaporator has successfully passed various tests, including lower power startup, thermal cycling, against gravity, and installation of flexible lines
- Thermal test data before and after vibration loading are very similar indicating the robustness of the 3D printed wick
- 3D printing bi-porous/ graded wick further simplifies the manufacturing process, as well as allows advanced wick design
- Current DMLS parameters is able to generate pore radius of 7 µm, further reduction of pore size may be achieved via smaller powder size

Acknowledgements

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