LHP Wick Fabrication via Additive Manufacturing

Bradley Richard, Devin Pellicone, William G. Anderson

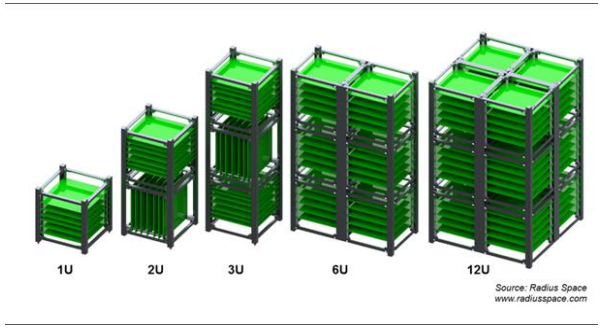
ADVANCED COOLING TECHNOLOGIES
The Thermal Management Experts | www.1-ACT.com

Presented By
Bradley Richard

Thermal & Fluids Analysis Workshop
TFAWS 2018
August 20-24, 2018
NASA Johnson Space Center
Houston, TX

Background

- CubeSats (10cm x10cm x10cm units) and SmallSats are becoming increasingly popular due to their lower development times and costs
  - NASA's Small Spacecraft Technology Program under the Space Technology Mission Directorate has been established to develop technology for CubeSats and other small spacecraft
- Advances and miniaturization of electronics has increased the capabilities of the CubeSat platform
  - Higher power components require a thermal management system

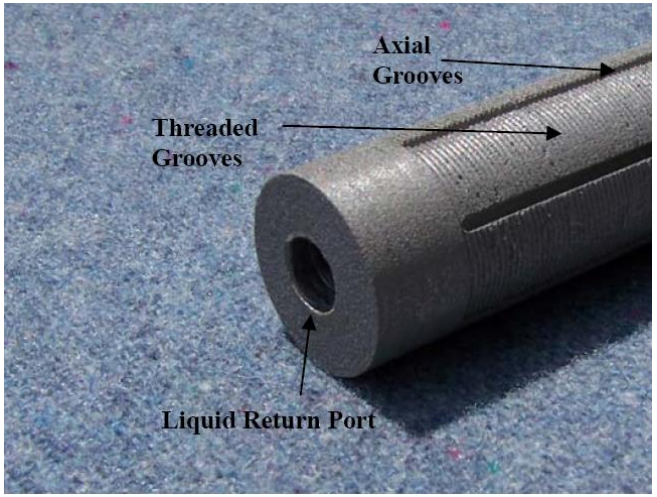


Motivation

- Loop Heat Pipes (LHPs) are a passive and flight tested solution
  - 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
- By using additive manufacturing the cost of LHP fabrication can be reduced
  - Eliminates machining of the wick
  - Less steps resulting in less labor and shorter fabrication time
    - Currently, primary wicks are tested to confirm performance after each step
- The goal of this work is to develop a low cost loop heat pipe (LHP) through additive manufacturing which can be used on CubeSats to increase the current maximum power levels of onboard instruments

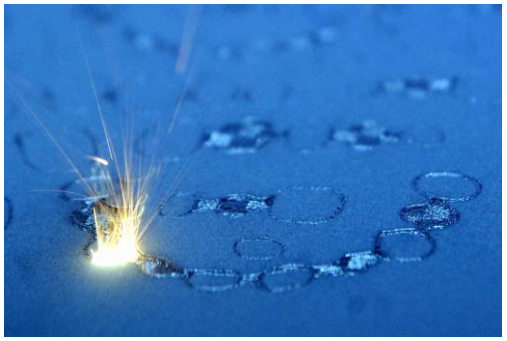
Current Primary Wick Fabrication

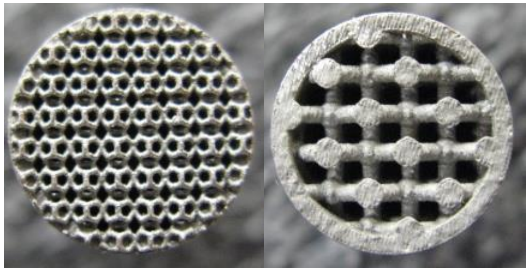
- Typical LHP wicks are metallic (nickel, stainless steel, monel, titanium) and have a pore size of approximately 1 micron
  - By comparison, the smallest pore size in heat pipe wicks is approximately 50 microns
- LHP Wick is sintered, then machined to fit into the LHP Evaporator
  - Tangential and axial vapor grooves must be machined into the wick
- Knife-edge seal is used to prevent backflow of vapor from primary wick to compensation chamber

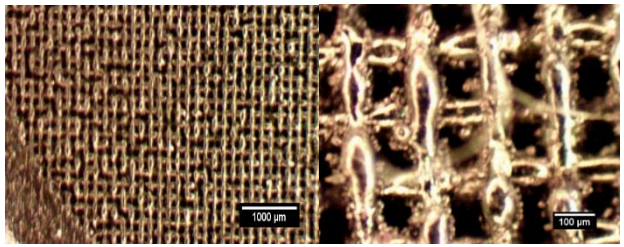


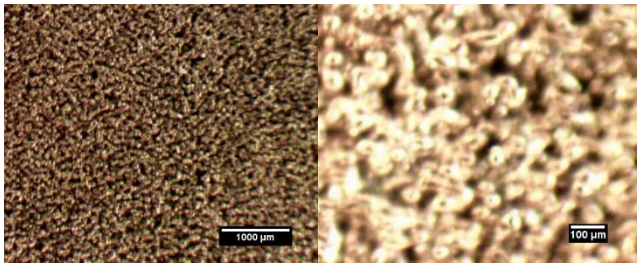
DMLS Wick Fabrication

- Direct Metal Laser Sintering (DMLS) is a process by which metal structures are made in a layer-by-layer sintering process that selectively melts powdered metal
- 316LSS can be used for 3D printing
  - Other common metals including aluminum and titanium are also available
- 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
- Vapor grooves do not need to be machined
- Wick can be fabricated within a fully dense envelope
  - Eliminates the need for a knife-edge seal
  - Eliminates wick insertion step









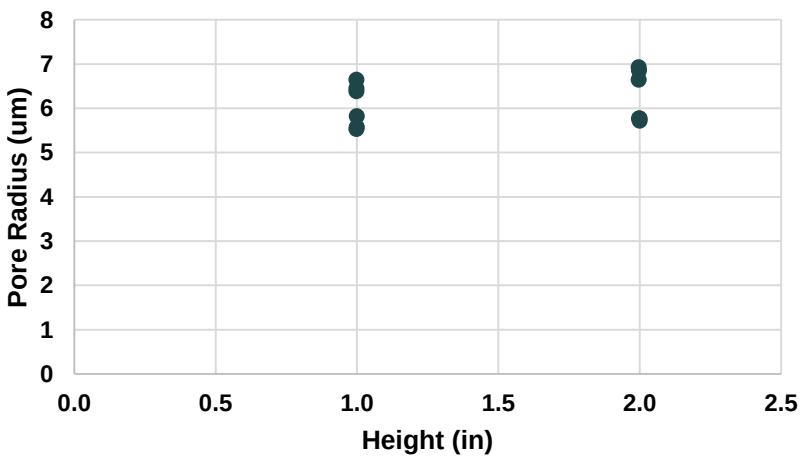
DMLS Parameter Optimization

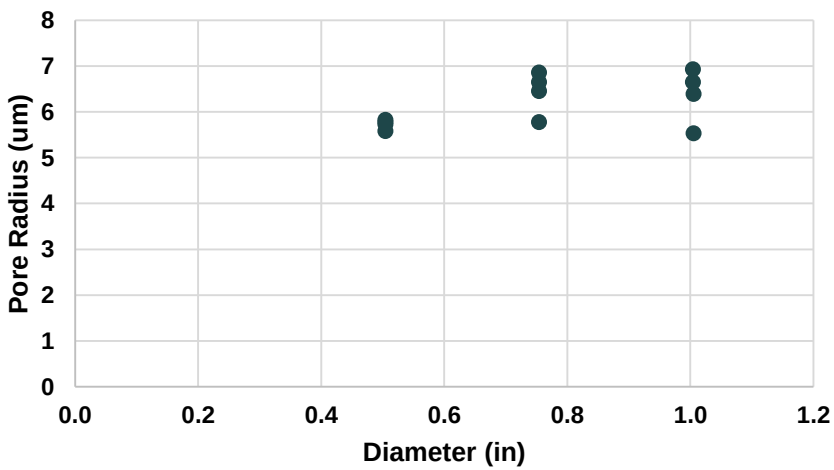
- Goal is to develop DMLS parameter set optimized for primary wick fabrication
  - Need pore radius <10µm for 100-200W power range
- Laser power, speed, and spacing varied between samples
- Sample 2 had smallest pore radius (5.6µm)
  - Chosen for fabrication of primary wick prototypes
- Limit on smallest pore size seems to be about 5µm
  - Further reductions in pore size will require using smaller diameter metal powder

Sample	Pore Radius µm
1	6.2
2	5.6
3	11.6
4	10.3
5	Hollow
6	Solid
7	Solid
8	Solid
9	6.0
10	8.8
11	Hollow
12	31.4
13	20.0
14	13.7
15	29.9

Scaling Study

- Optimization study was completed on small scale samples
  - 1” in length, 0.5” in diameter
- First primary wick prototype will be larger, 4” in length and 1” in diameter
  - Need to verify no negative effects on wick properties due to possible increase in thermal stress during fabrication
- No change in pore size based on size of part detected



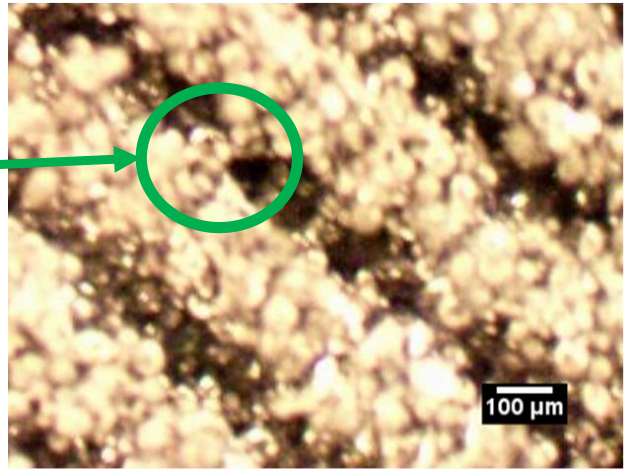


Secondary Wick Fabrication

- Ability to 3D print secondary wicks would allow for one step fabrication of entire LHP evaporator
- Need a much larger pore size than with primary wick
  - Targeting a pore radius of 50µm
- Four new parameter sets tested
  - Measured same pore size as primary wicks
- Additional testing and optimization required

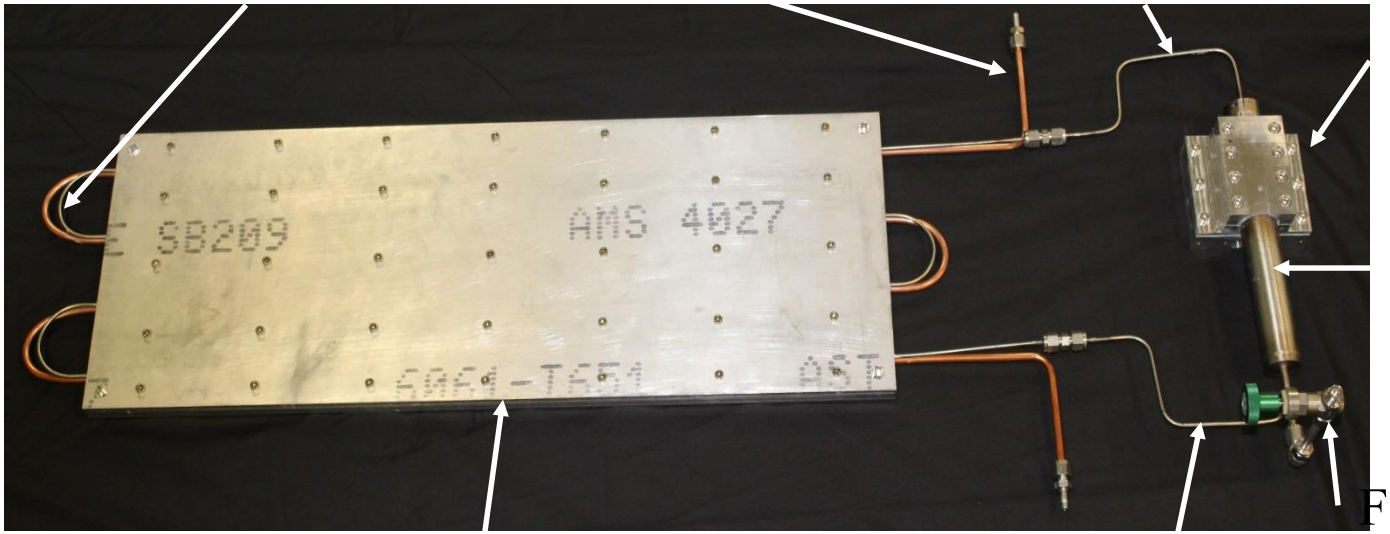
Parameter Set	Pore Radius um
1	5.6
2	5.8
3	5.5
4	5.0

Larger pores blocked off resulting in smaller measured pore size



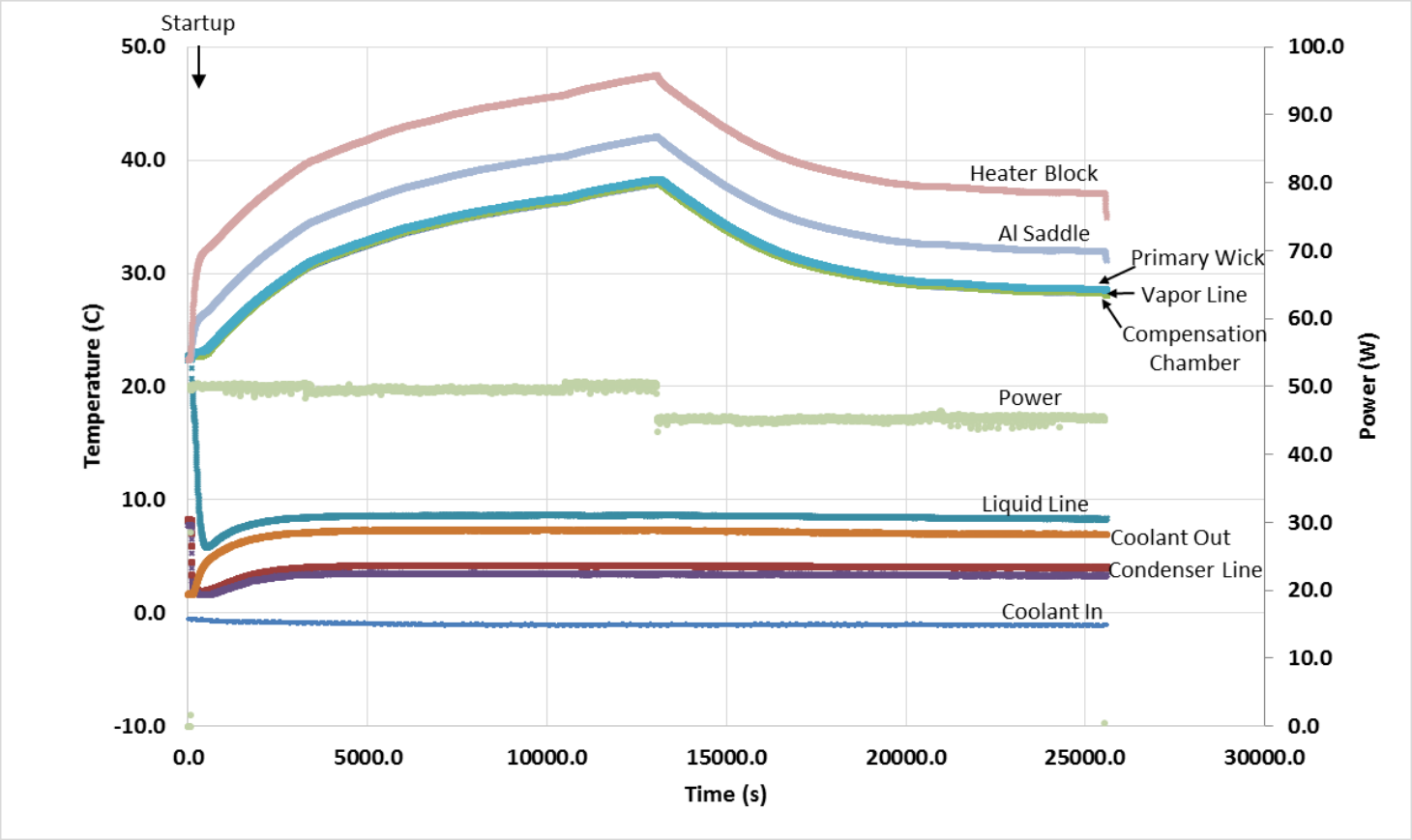
1st Generation Prototype Fabrication

- Compensation chamber and vapor line welded onto primary wick
- All parts in contact with ammonia are 316SS
- Condenser length of 3m
- Charged with 35g ammonia
- Primary wick pore radius of 44µm
  - Later discovered to be due to use of PH1SS metal powder



1st Generation Prototype Testing

- Maximum power of 45W
  - Low due to 44µm primary wick



2nd Generation Prototype Fabrication

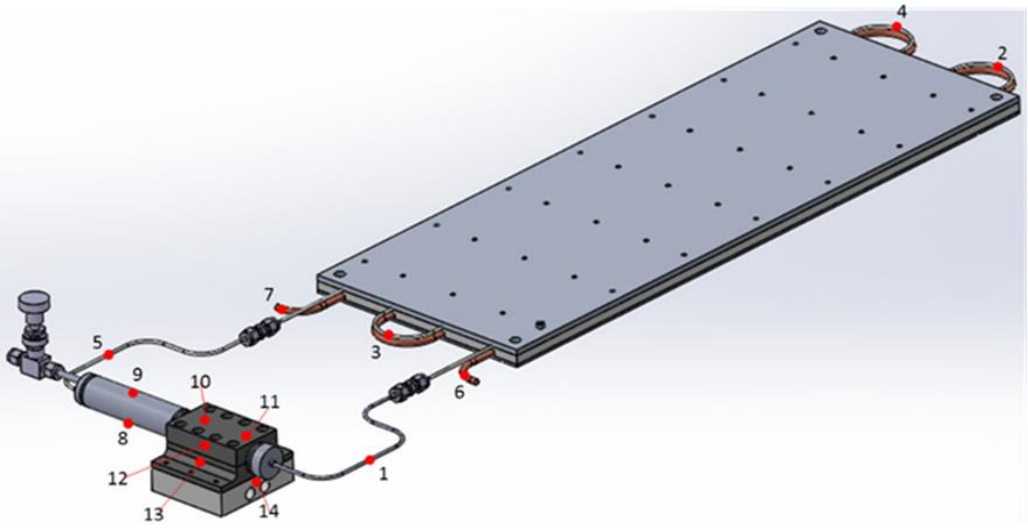
- Primary wick printed using newly optimized parameter set and 316LSS
  - Pore size of 7µm as expected from small scale wick samples
  - Envelope was confirmed to be hermetic
- Same condenser and compensation chamber used as on previous prototype

Primary Wick	He Leak Rate	Pore Radius
	std cc/sec	um
1	2.1E-10	7.2
2	1.2E-09	6.7

2nd Generation Prototype Testing

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

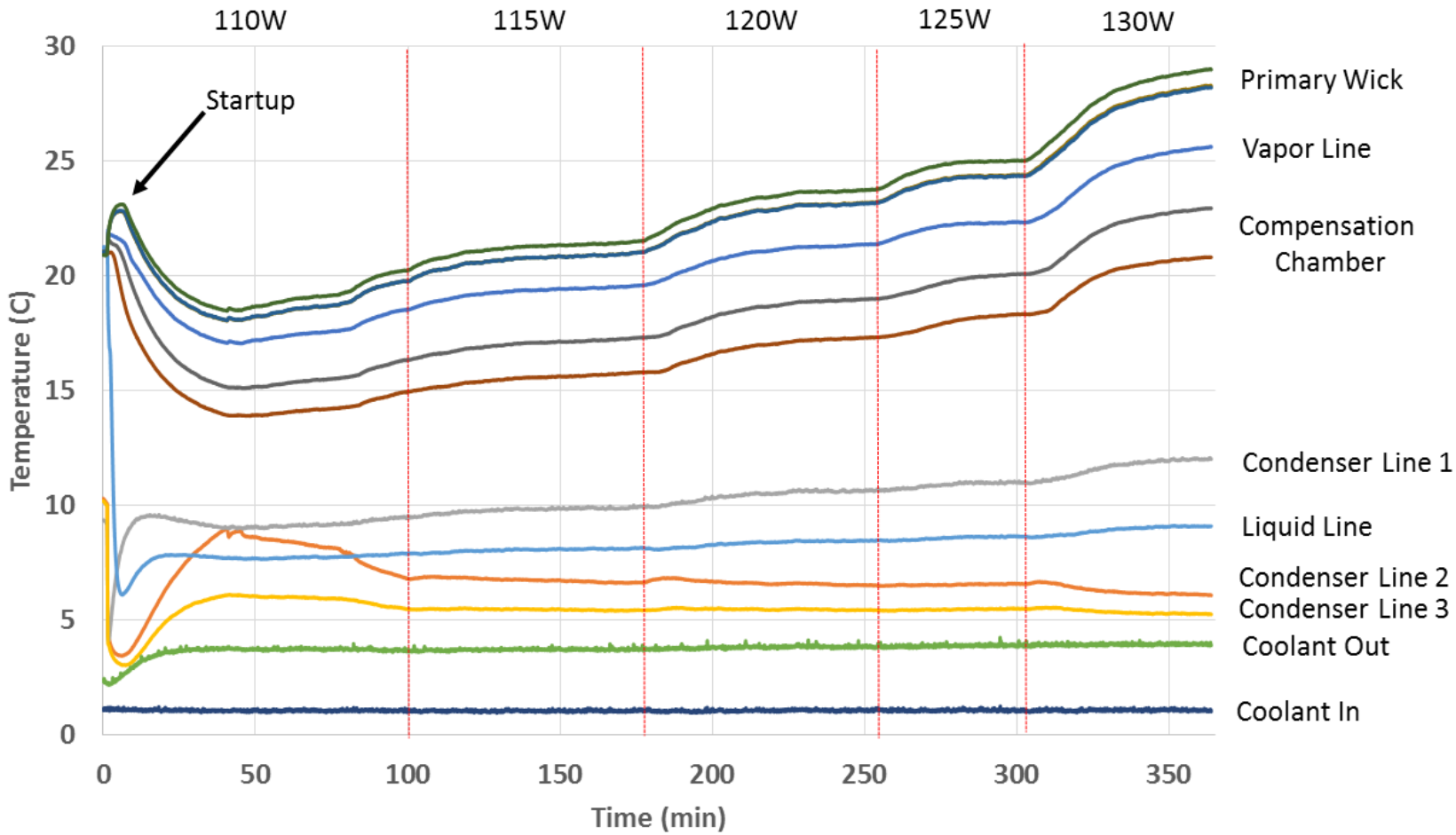
- Test Conditions
  - Sink Temperature: 0°C
  - Adverse Elevation: 12mm
  - Steady State Test
    - Power Increased in 5W increments
    - Used to determine maximum power
  - Low Power Startup
    - Power set to 5W
    - Used to verify low heat leak



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

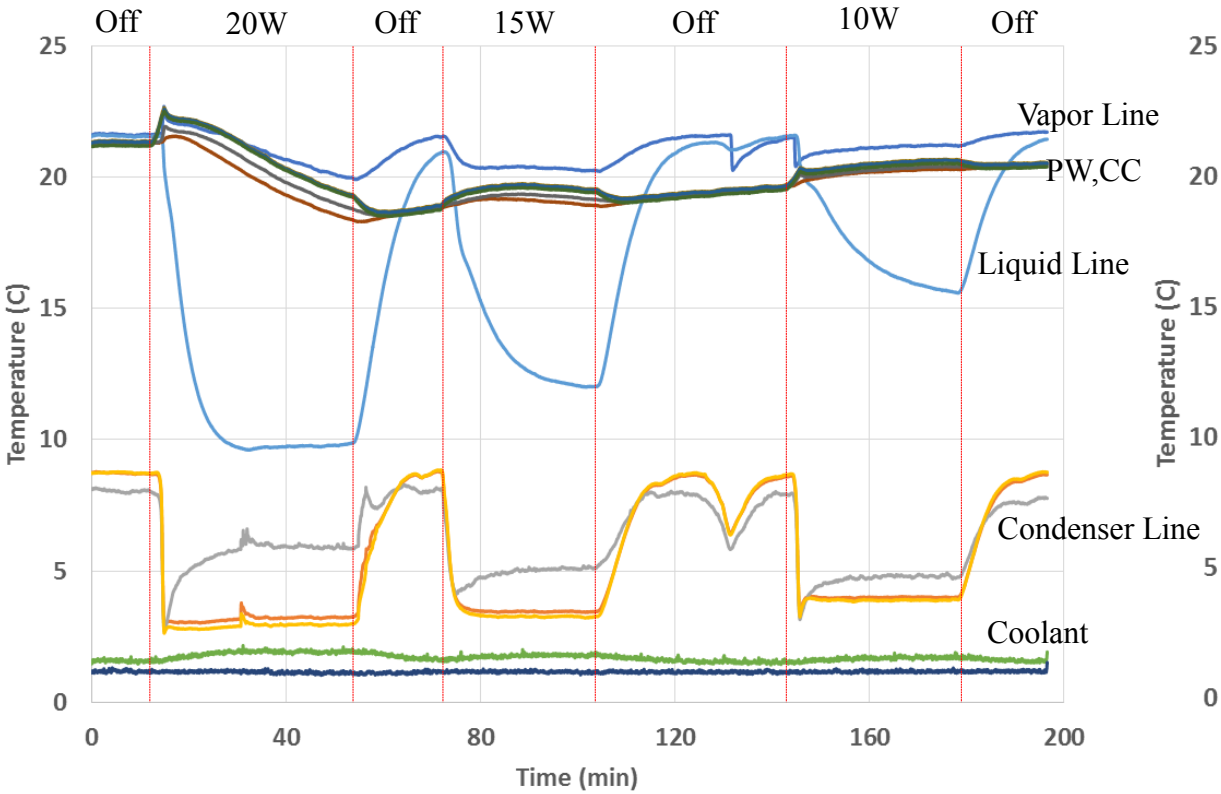
2nd Generation Prototype Testing

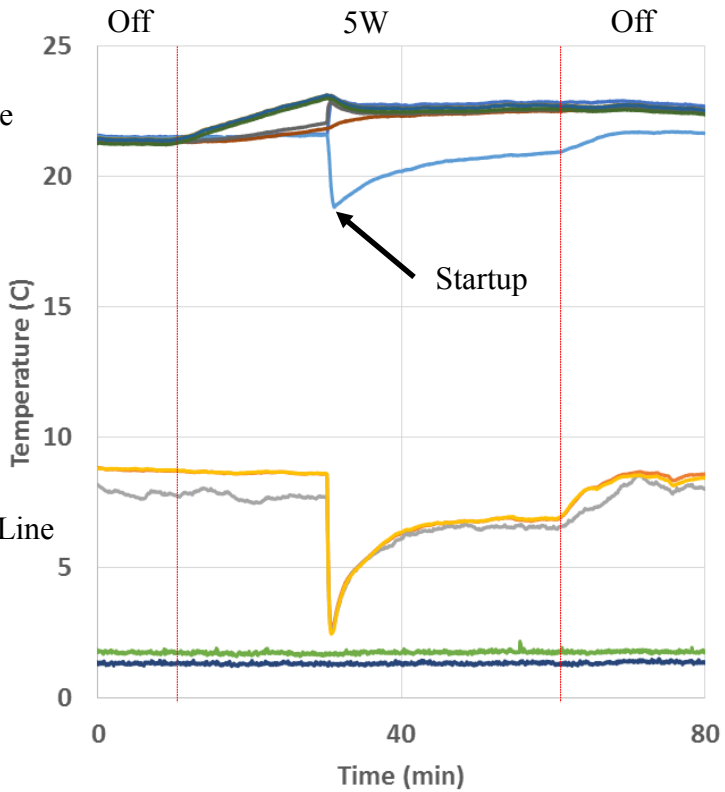
- Maximum power of 125W before dry-out



2nd Generation Prototype Testing

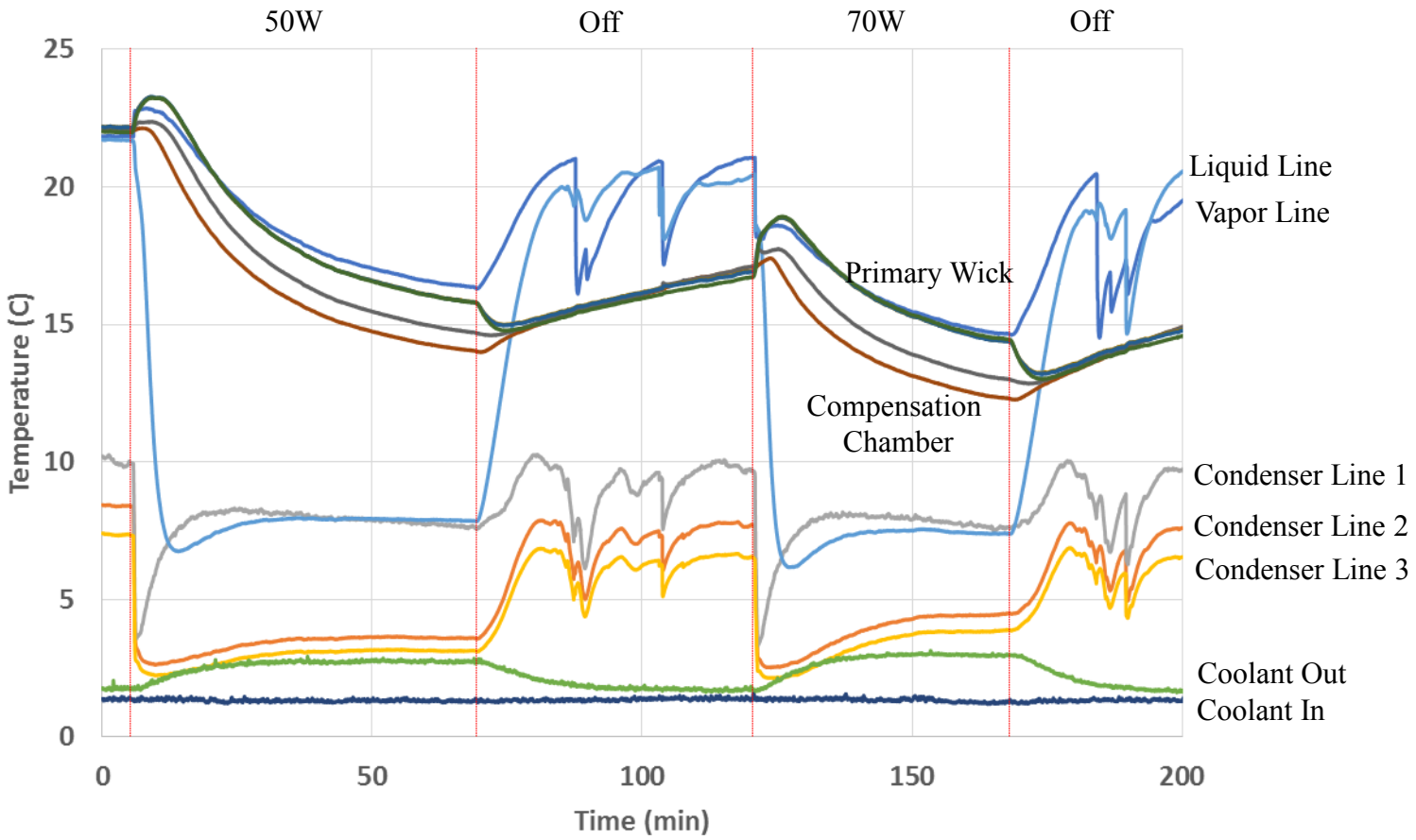
- Successful startup at power as low as 5W
  - Indicates that there is not a significant amount of heat leak
    - Large enough pressure difference between evaporator and compensation chamber
- Startup was immediate at heat loads of ≥10W





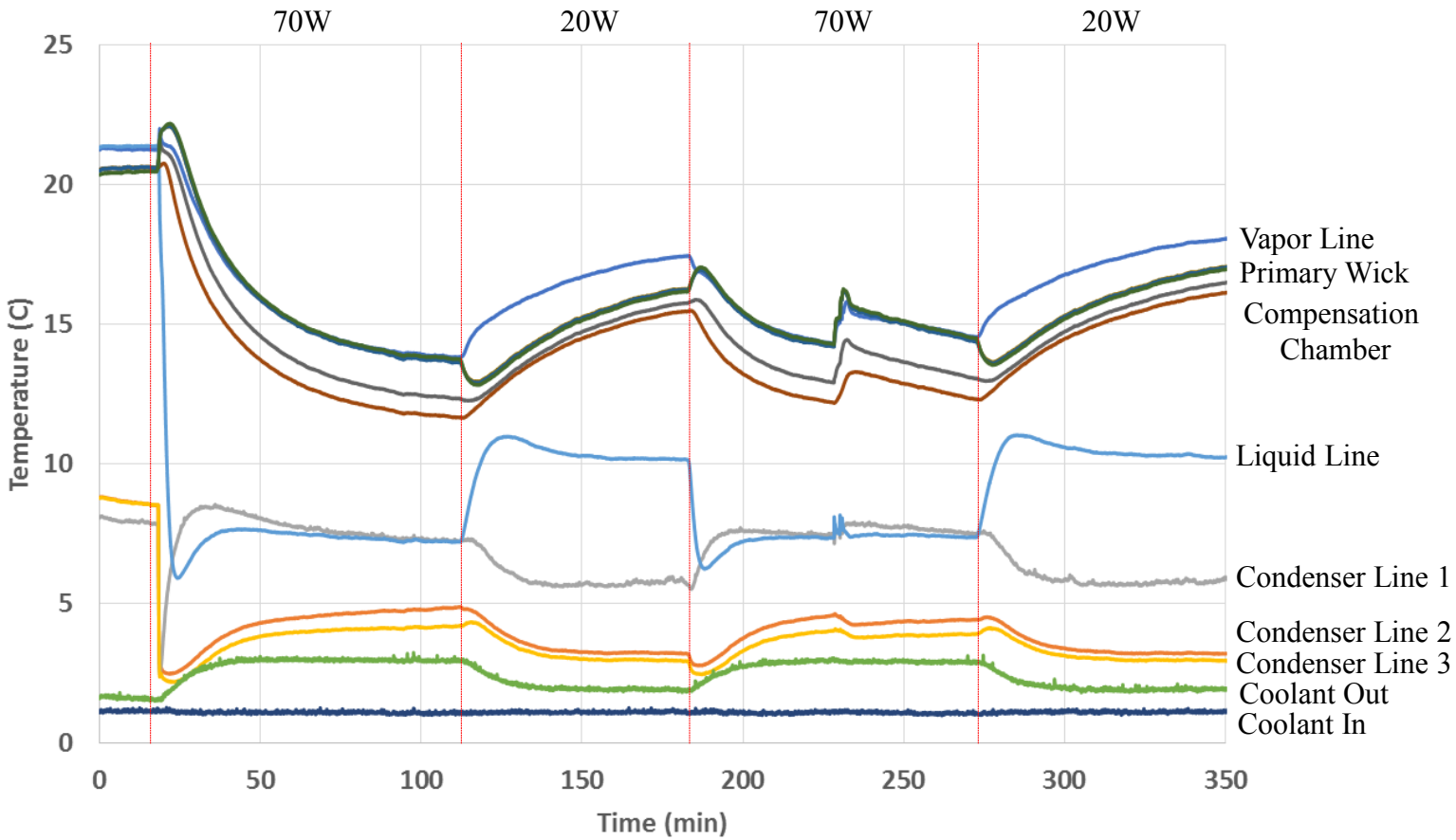
2nd Generation Prototype Testing

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



2nd Generation Prototype Testing

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



Future Work

- Continuation of secondary wick DMLS parameter study
  - Increase pore size of wicks
- Optimization of 3D printed primary wick design
  - Miniaturization to reduce weight and volume
  - Reduced thermal resistance
  - Reduced pressure drop
- Repeatability study on 3D printed wicks
- Life testing of 3D printed wicks

Summary

- Optimization of DMLS parameters for primary wicks resulted in wick structure with a pore radius of 5-7µm
- Scaling of parts was confirmed to not have and adverse effect on 3D printed wick properties
- Optimization study for secondary wick fabrication has begun
  - Further development is needed to increase pore size
- 2nd generation prototype achieved a maximum power of 125W
  - 3D printed primary wick had pore radius of 7µm

Acknowledgements

- This work was completed under a Phase II SBIR program sponsored by NASA Marshall, LHP Wick Fabrication via DMLS, Contract No. NNX16CM46P. Dr. Jeffrey Farmer was the Technical Monitor.
- Supported at ACT by Bill Anderson, Devin Pellicone, Greg Hoeschele, and Sebastian Lafever