3D Printed Wick Development for Loop Heat Pipes

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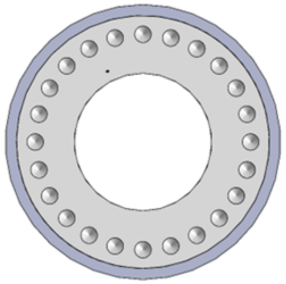
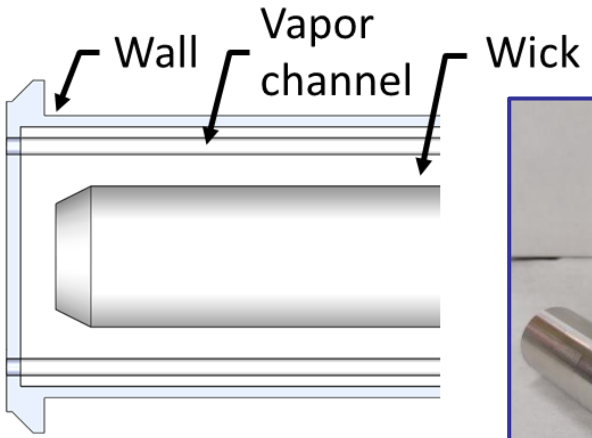
Introduction

- Conventional LHPs have high costs and long lead times due to labor-intensive evaporator fabrication
- ACT has fully-automated evaporator fabrication using Laser Powder Bed Fusion (LPBF)
- Significant savings in cost and lead times; a low-cost, flexible thermal link for SmallSats





	Standard LHP	3DP LHP
New Design (EDU, Qual, etc.)	\$200k-\$500k	\$100-\$200k
Development Time	12+ months	6+ months
Recurring (Acceptance Testing only)	~\$100k	~\$40k
Recurring Lead Time	8+ months	4+ months

ROM for comparison purposes, assuming similar testing requirements

Introduction

- Previous presentation (Gupta et al., 2021) provided an overview of the 3D printed evaporator development

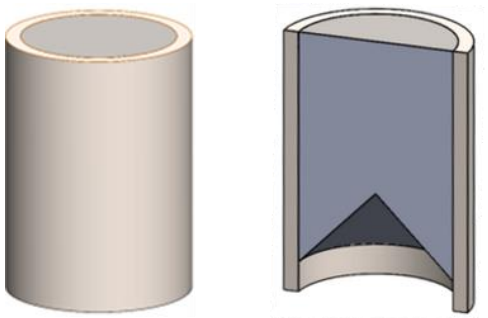
- Current presentation focuses on the details of the wick development

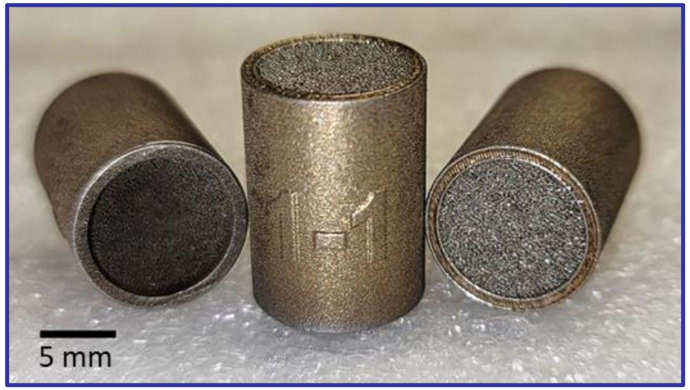
Contents

- Wick Build
- Wick Characterization
  - Methods
  - Results
  - Pressure Margin
  - Loose Powder Ejection
- Conclusions
- Current Work

Wick Build

- A standard wick sample geometry selected for parameter development
  - Design includes a solid wall to incorporate the bi-porous transition
  - Wick region offset from the build plate to avoid EDM cut



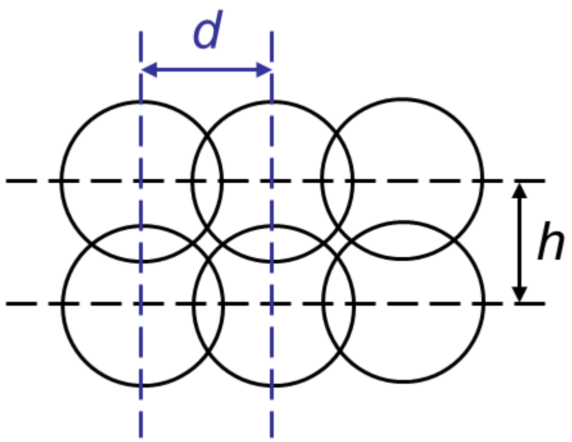


- All wick samples built with recycled 15-50 µm 316L SS powder

- Porosity introduced through controlled lack-of-fusion by varying an "energy density" in LPBF

$$\boxed{E_\rho = \frac{Pt}{hdl}}$$

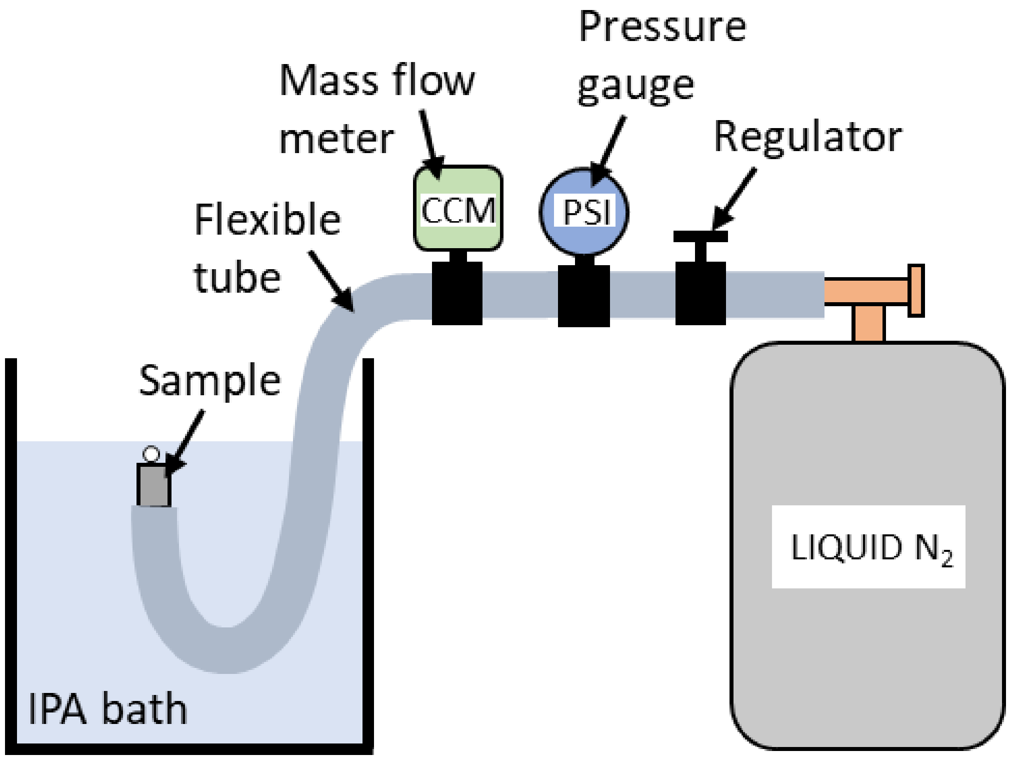
P = laser power
t = exposure time
h = hatch distance
d = point distance
l = layer thickness



Wick Characterization – Methods

- Energy density increased in steps; each wick characterized by three parameters:
  - Max. eq. pore radius (r_{eq})
  - Permeability (k)
  - Connected porosity

- Experimental methods:
  - Bubble-point test → r_{eq}
  - Dry flow test → k
  - Mercury Intrusion Porosimetry → connected porosity



During flow test, sample was not submerged in IPA bath

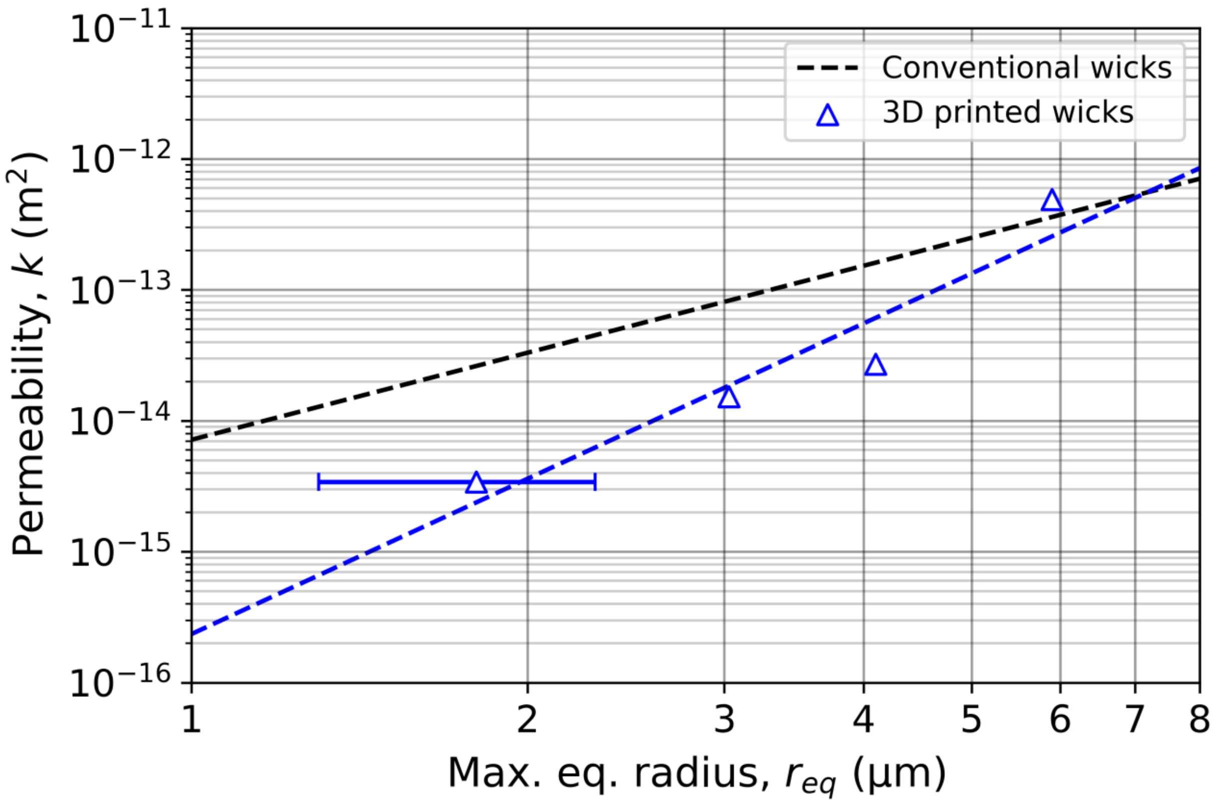
Wick Characterization – Results

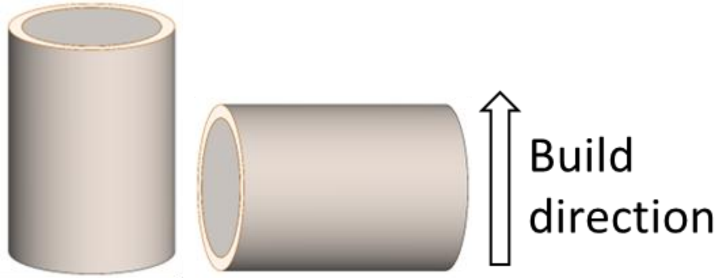
- Energy density below 0.67 J/mm^3 found to lead to complete build failure
- Loose powder ejected during ultrasonic cleaning between 0.67 J/mm^3 and 1.09 J/mm^3
- Complete build success at 1.09 J/mm^3 and beyond, with increasingly dense samples

Energy density, E_ρ (J/mm^3)	Max. eq. radius, r_{eq} (µm)	Permeability, k (10^{-14} m^2)	Connected porosity (%)
5.08	1.8 ± 0.5	0.34 ± 0.03	8.56
3.57	3.03 ± 0.04	1.53 ± 0.06	9.68
2.22	4.1 ± 0.1	2.7 ± 0.2	27.02
1.09	5.9 ± 0.2	49 ± 5	43.97
0.90	Loose powder ejection		
0.83	Loose powder ejection		
< 0.67	Build failed		

Wick Characterization – Results

- Wicks with max. pore radius of ~2 μm successfully developed in this program
- 3D printed wick permeability generally trends lower than conventional wicks
- Build direction has no significant effect on the capillary properties; i.e., wicks are isotropic



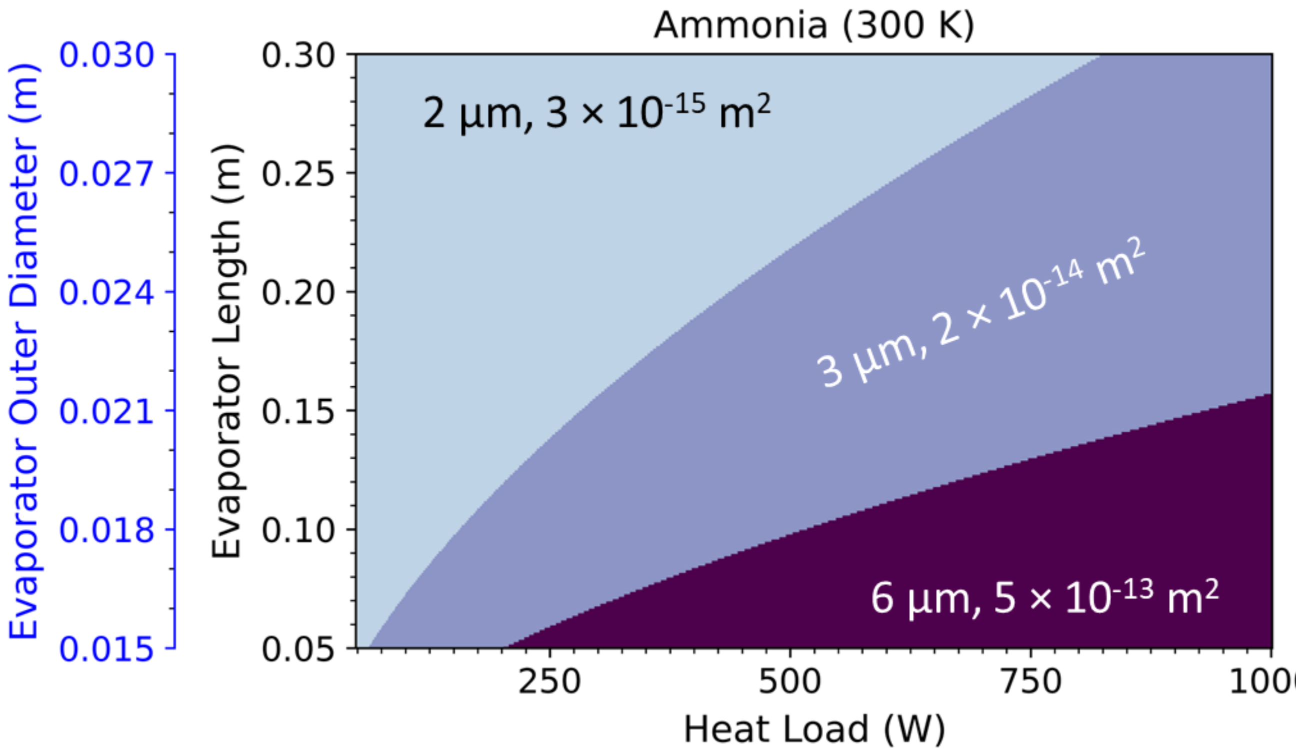


Wick Characterization – Pressure Margin

- Appropriate wick choice will depend on pressure margin; Pressure margin = Wick capillary pressure – Wick pressure drop

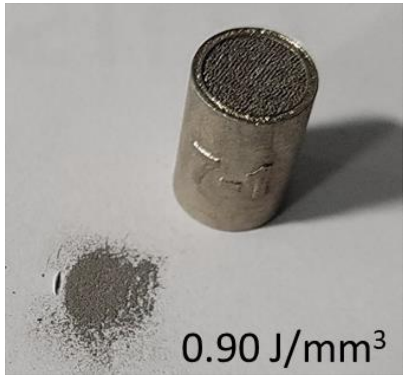
- Pressure margin depends upon max. pore radius, permeability, wick size, nominal heat load, etc.

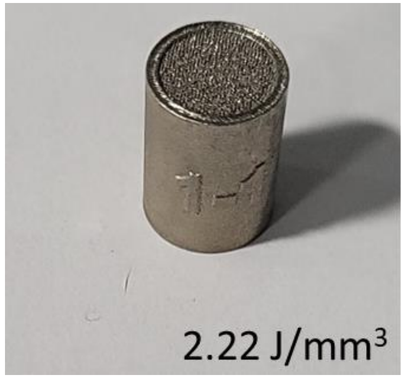
- For similar pressure margin, a high porosity wick will have lower heat leak, better thermal conductance

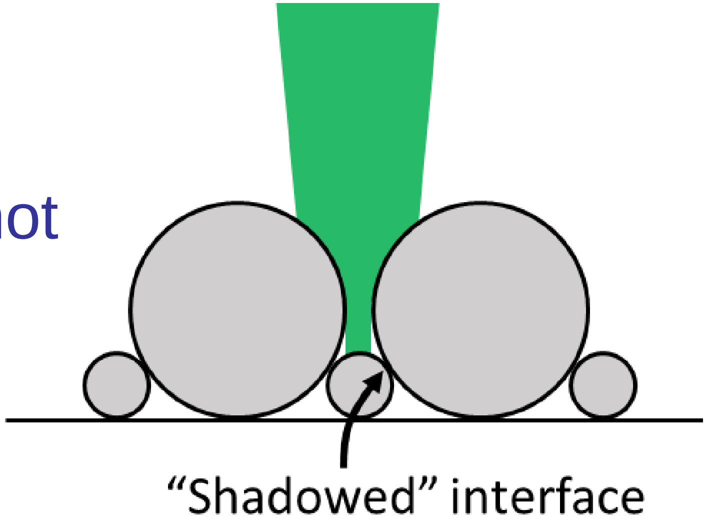


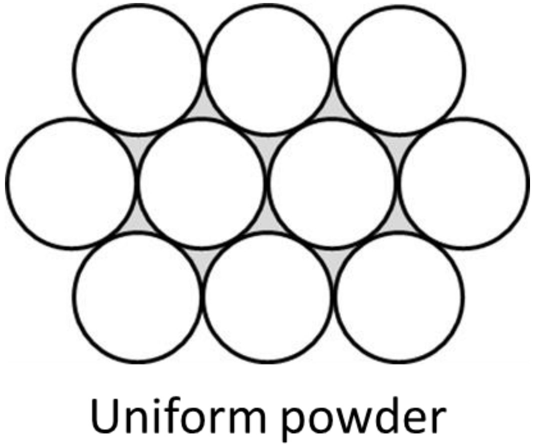
Wick Characterization – Loose Powder Ejection

- Wick samples between 0.67 J/mm^3 and 1.09 J/mm^3 seen to eject loose powder
- With mixed 15-50 µm powder, large particles can potentially “shadow” smaller particles
- At low E_ρ, smaller particles may not fuse → ejected through gaps between larger particles
- Avoided with uniform powder







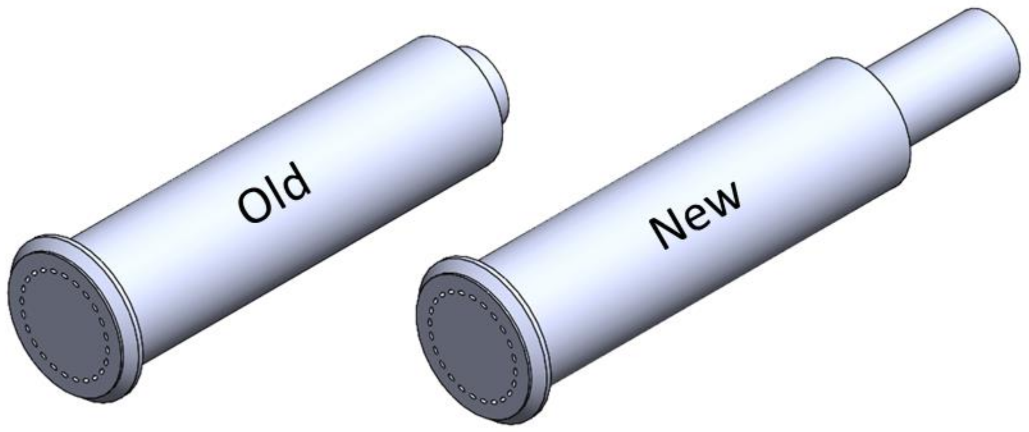


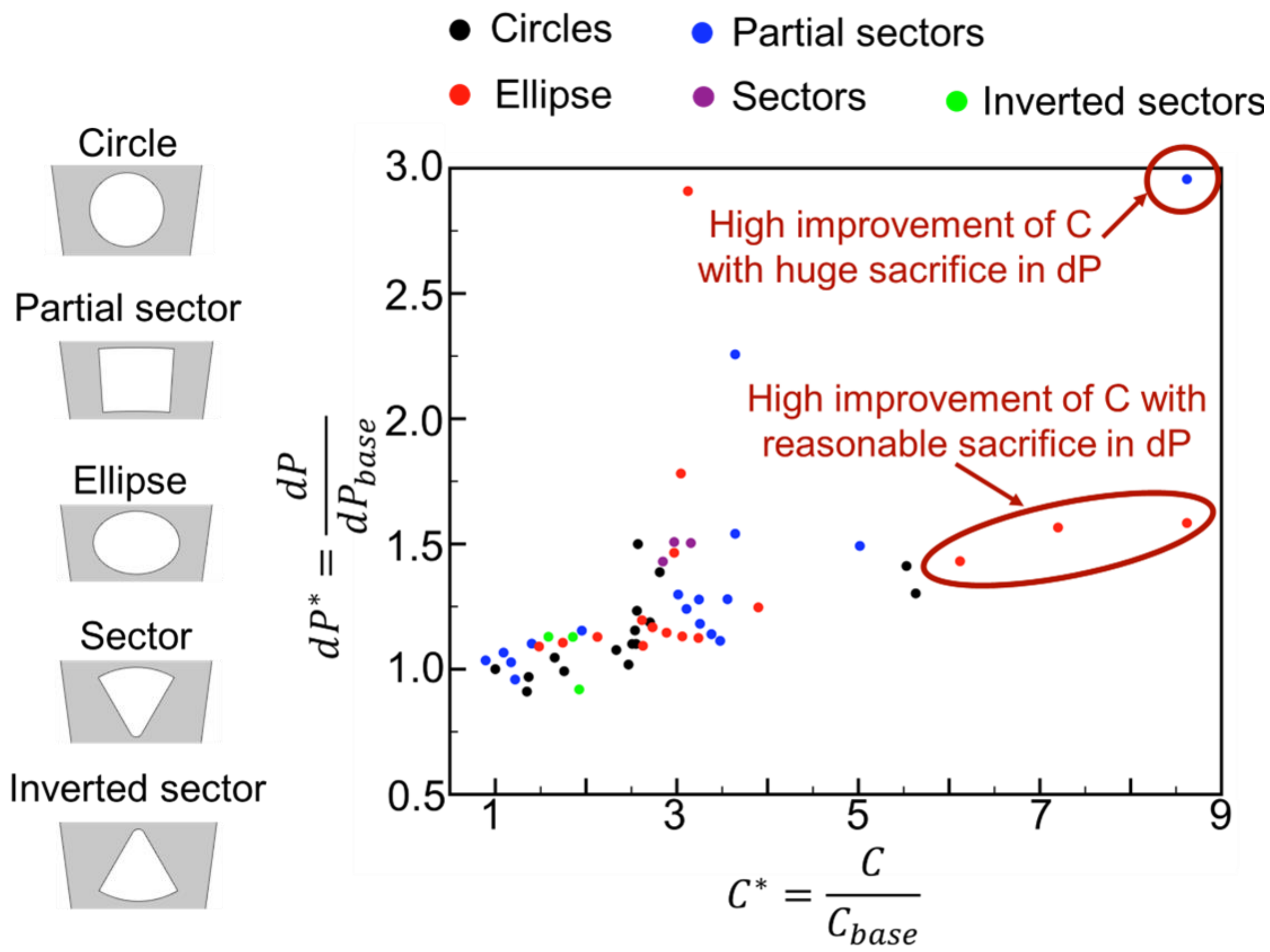
Conclusions

- 3D printed wicks with controlled porosity printed by modulating the energy density in LPBF
- Wick builds successful above a threshold energy density
- Overall, max. pore radius of 2 – 6 µm, permeability of 10^{-15} to 10^{-12} m^2, and porosity of 9% to 44%
- Appropriate wick choice depends on pressure margin; higher porosity wick preferred for similar pressure margins
- Current work to serve as guideline for 3D printed wick development

Current Work

- New evaporator design and testing for improved conductance
  - Improved vapor groove geometry
  - Circumferential vapor channels
  - Thinner wall (subject to structural constraints)
  - Larger gap to CC





Current Work

- Mini LHP development for CubeSats (1.5-inch evaporator)
  – under NASA Phase II SBIR

- Larger system (4-inch evaporator) with integrated DRP under development for ESPA-Sat
  – under USAF Direct to Phase II SBIR

- Pursuing opportunities for sustained microgravity testing