Review of Cryogenic Loop Heat Pipe Technology Development by NASA/GSFC for Space Applications

Triem T. Hoang
TTH Research Inc.
Clifton VA 20124

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Outline

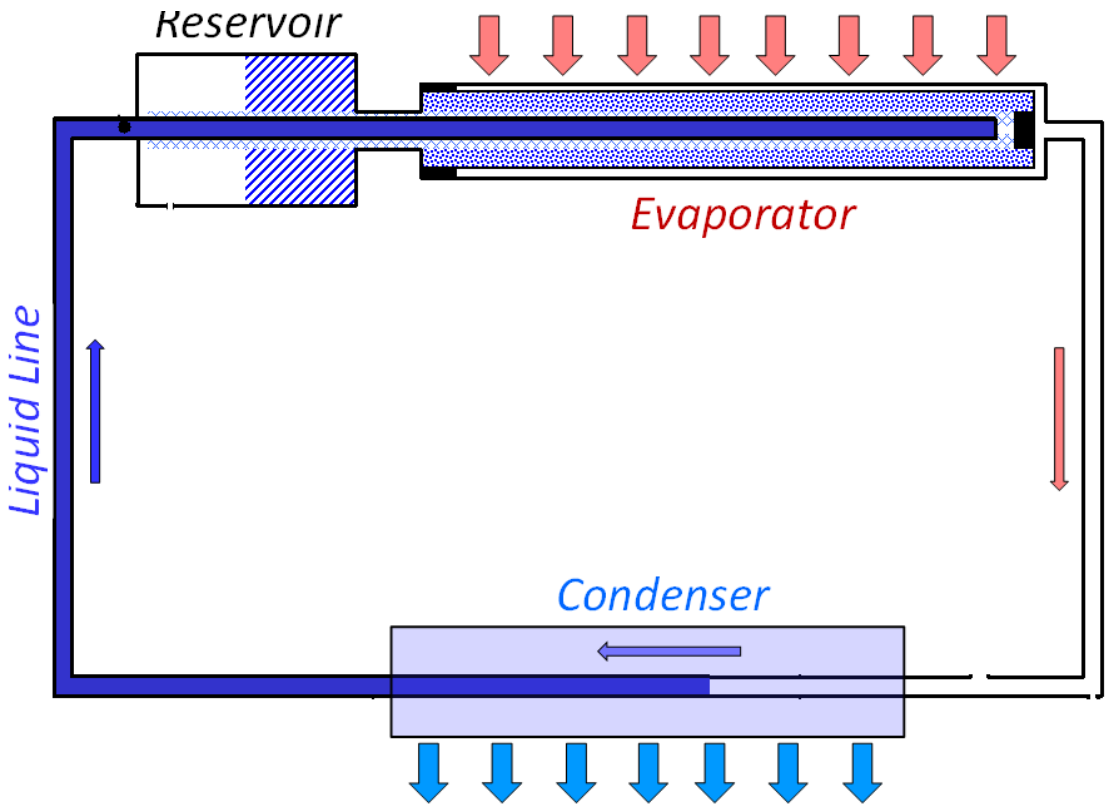
- Two-Phase Capillary-Pumped Heat Transport Technology
- Unique Operational Requirements for Cryogenic Systems
- Cryogenic Advanced Loop Heat Pipe Design
- Flexible N2-ALHP Proof-of-Concept Demonstration
- H2/Neon-ALHP Proof-of-Concept Demonstration
- He/Neon-LHP Large-Area Cryocooling
- Summary/Conclusion

Acknowledgements

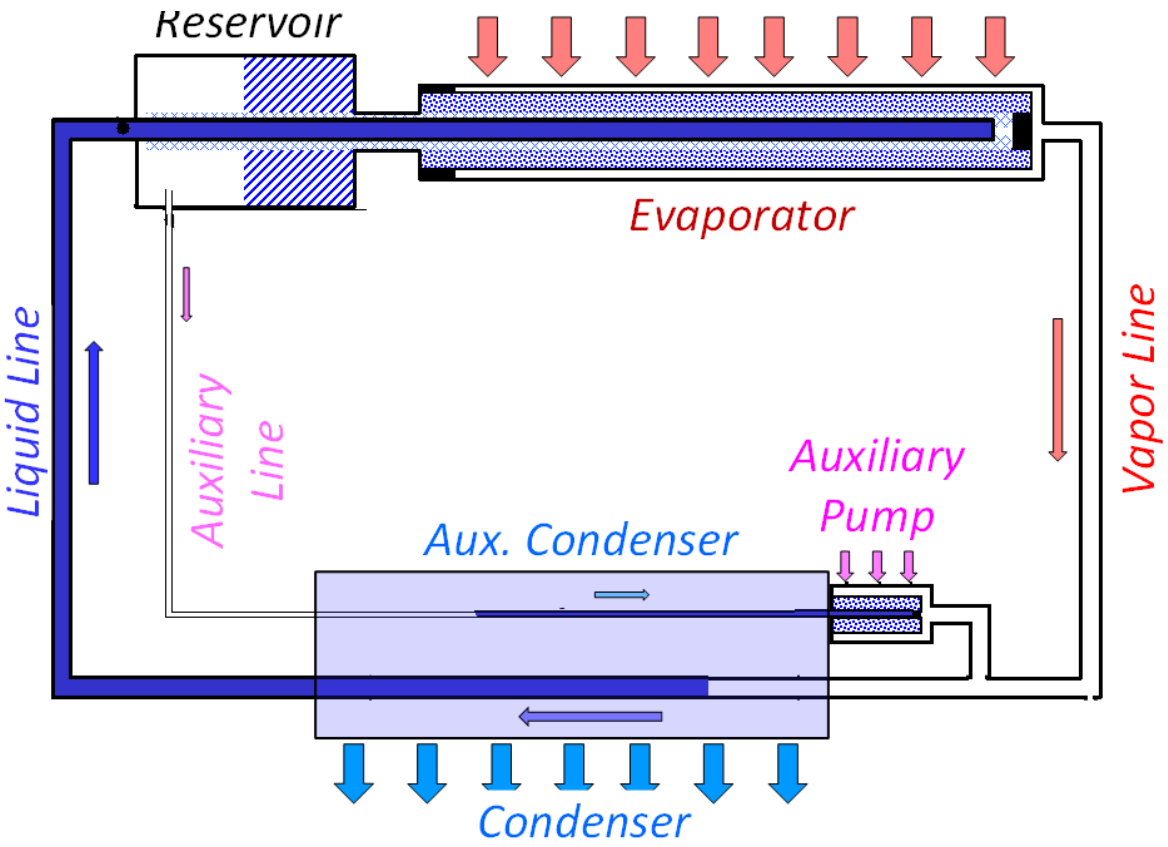
1. *The research presented herein were supported by NASA/GSFC under the SBIR program from 2000 to 2005 except the flexible N2-ALHP which was funded by the U.S. Department of the Air Force under Contract No. F29601-01-C-0039.*

2. *As a project team member (subcontractor), Thermacore of Lancaster, PA was responsible for the design/fabrication/processing and instrumentation of the proof-of-concept demonstration test units. All tests were also performed at Thermacore facility.*

Two-Phase Capillary-Pumped Heat Transports



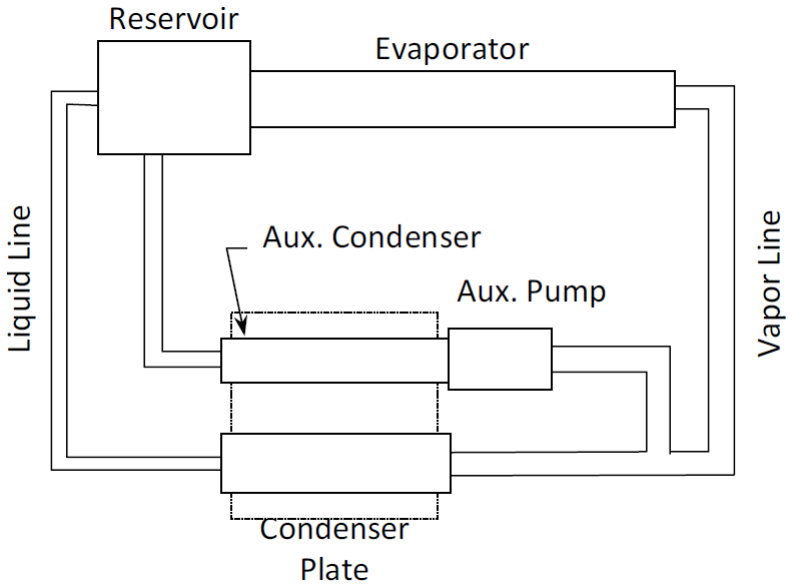
Conventional Loop Heat Pipe

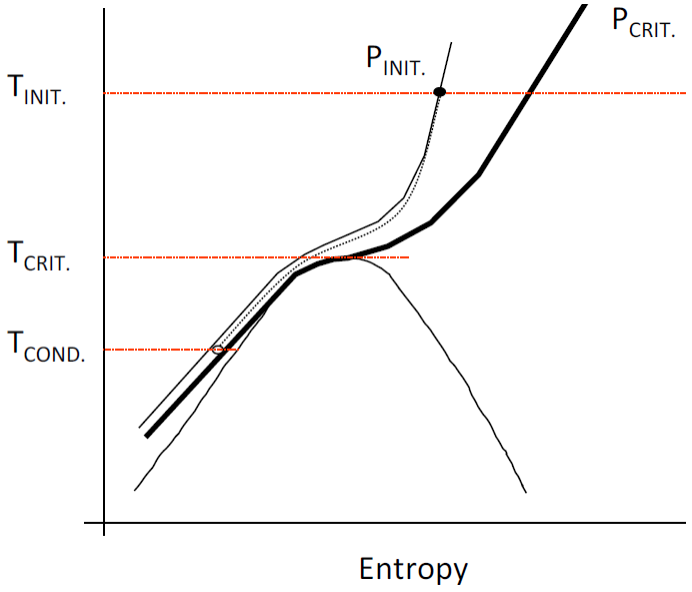


Advanced Loop Heat Pipe

U.S. Patent No. 6810946 (2004)

Unique Requirements of Cryocooling Transport





Fast Start-ups from Supercritical Condition

- pressure & temperature above respective critical values
- no extraneous mechanism available

Pressure Reduction at Room Temperature

- safe processing/handling/transport
- utilization of existing hardware design and fabrication techniques

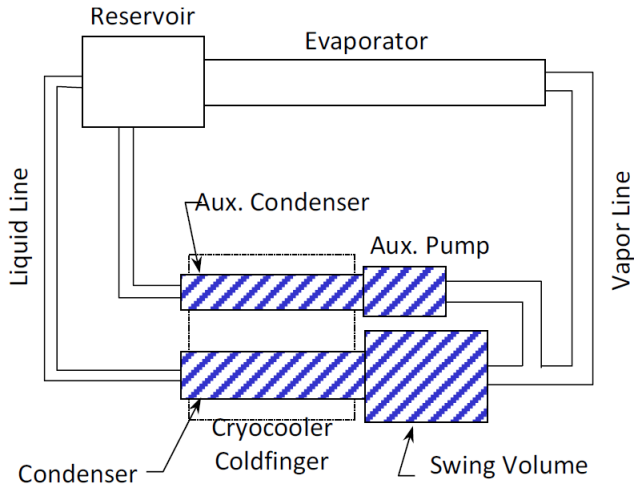
Environmental Heating

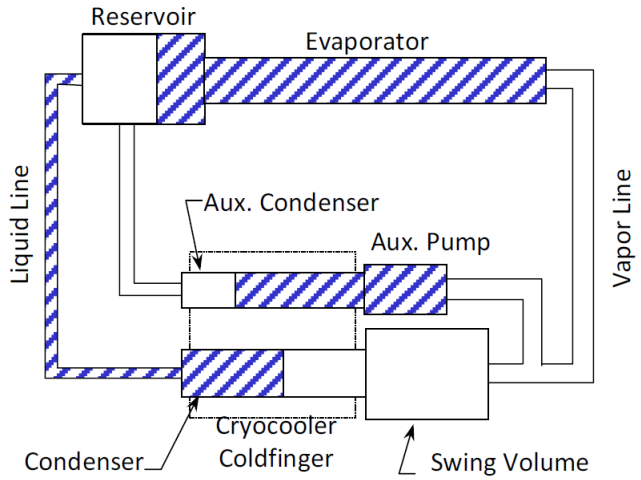
- manage parasitics in hot surrounding
- prevent loop shutdown during standby

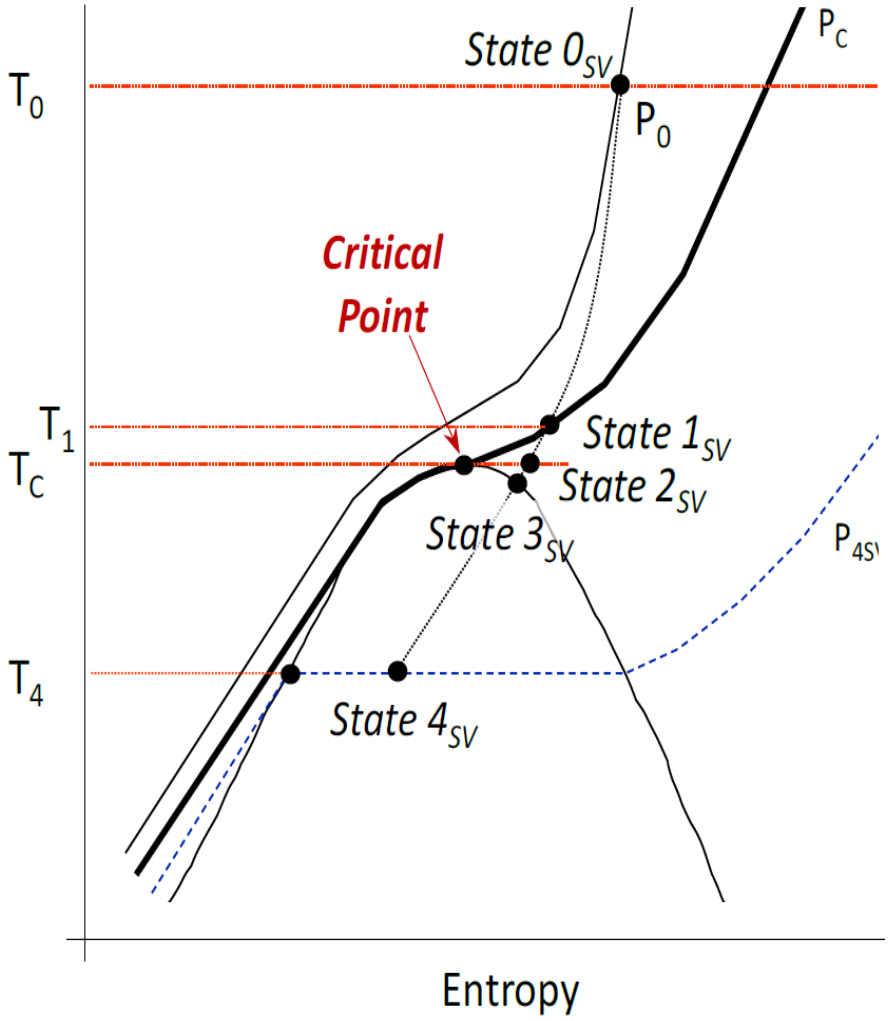
Others

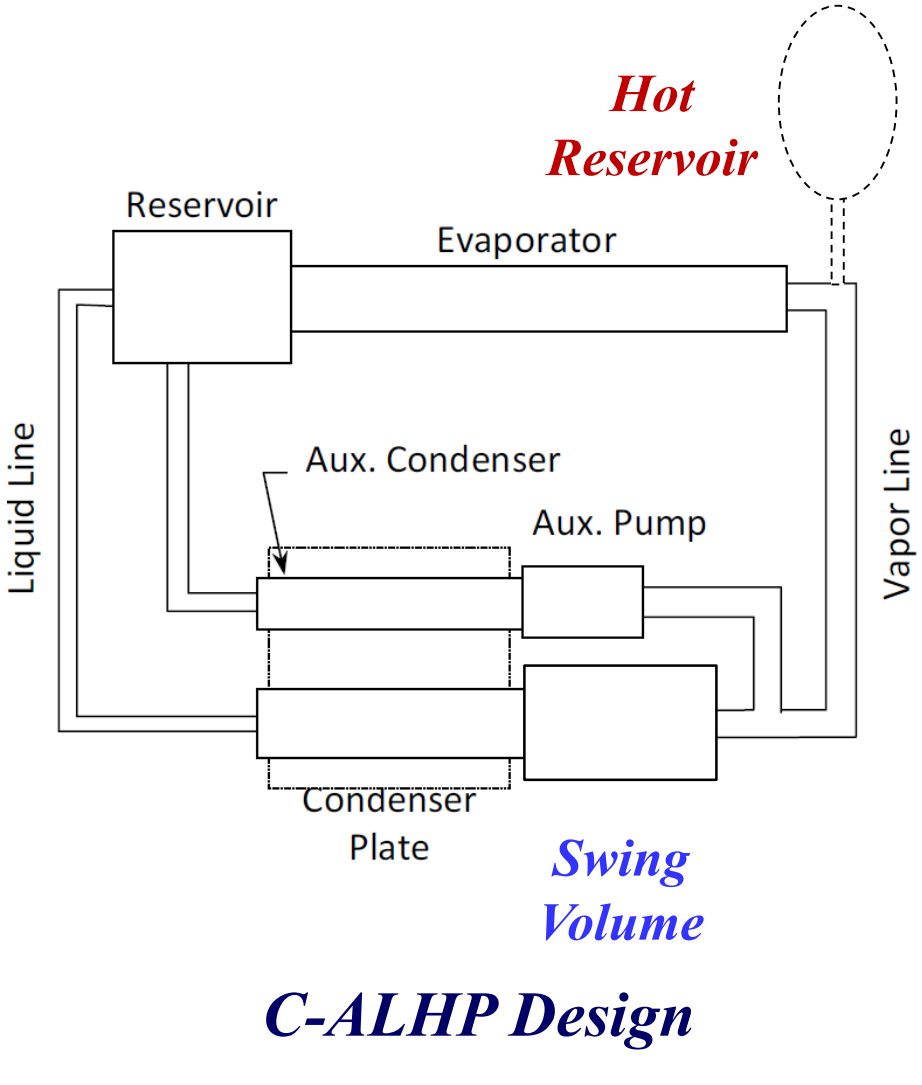
- flexibility for across-gimbal cryocooling
- CTE mismatch
- metal hardening at cryogenic temperatures

Cryogenic Advanced Loop Heat Pipe



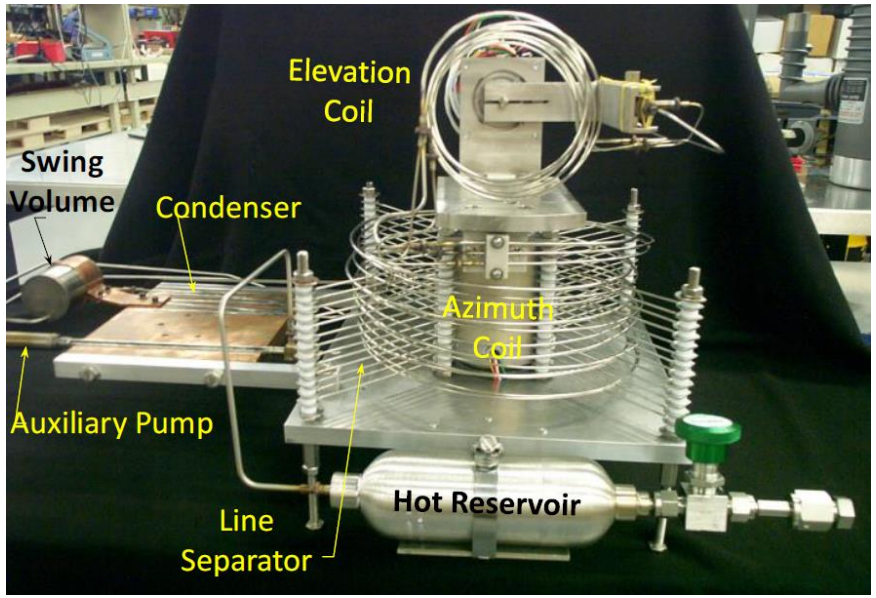






C-ALHP Design

Flexible N2-ALHP for Across-Gimbal Cryocooling



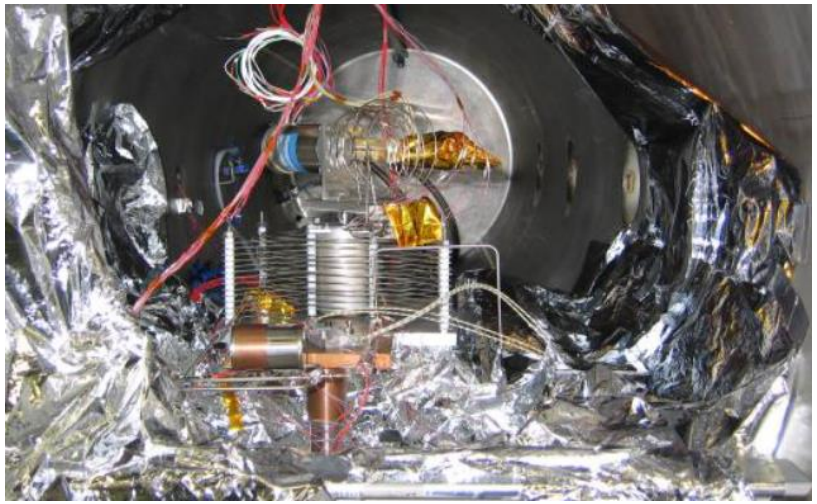
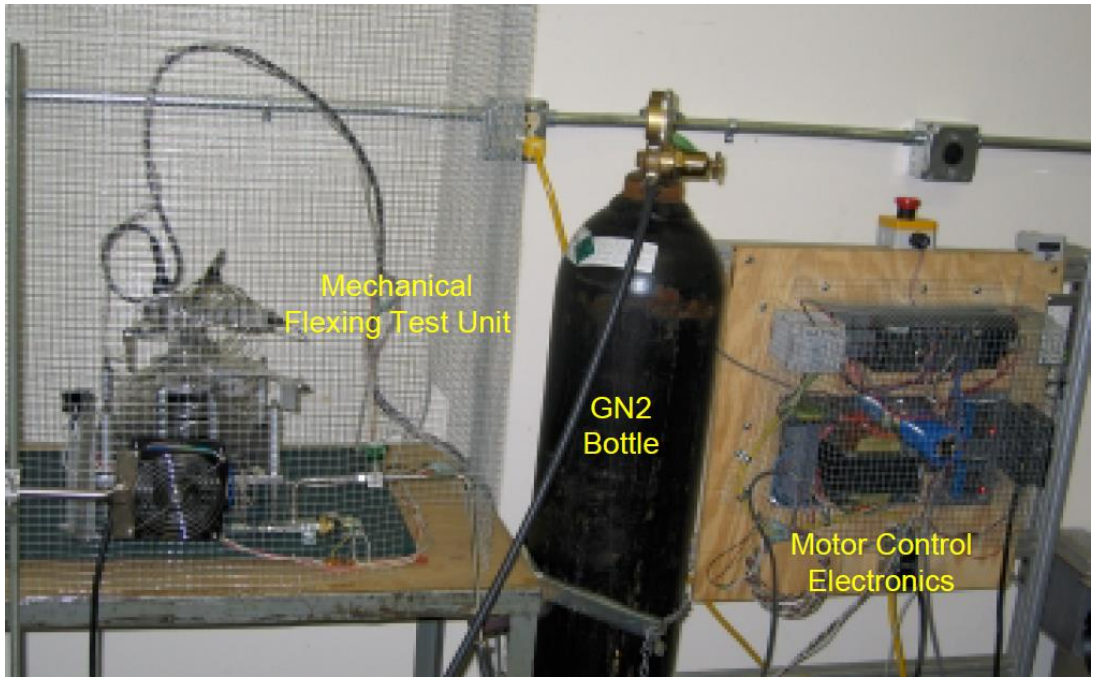
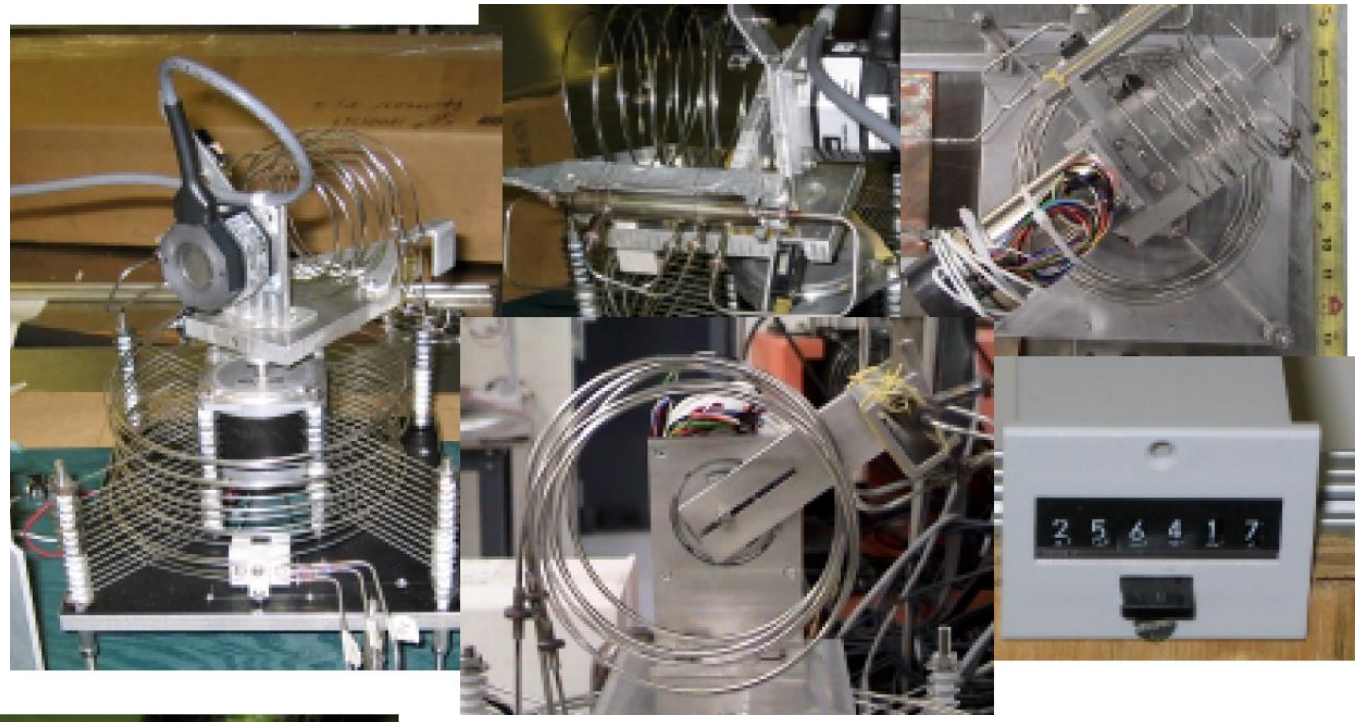


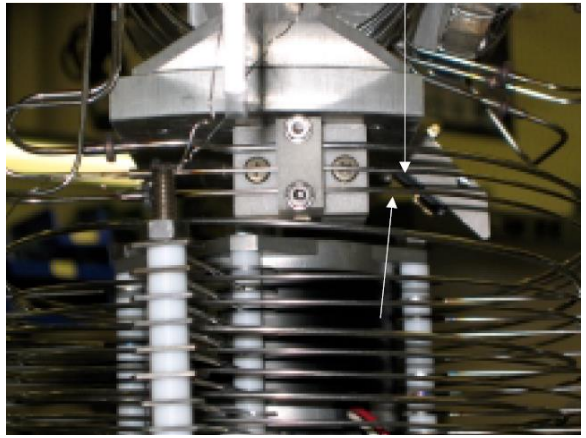
Table 1. Volume Breakdown of N2-ALHP Components

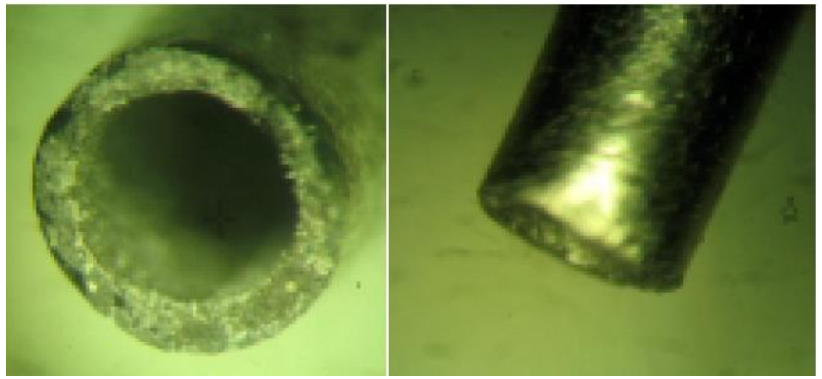
Components	Description	Vapor (cc)	Volume 2-ϕ (cc)	Liquid (cc)
Primary Capillary Pump				
- 1.4 micron wick	0.43"ODx4mmIDx1.36"Lx0.40porosity			1.3922
- vapor grooves		0.5320		
- reservoir	0.5"ODx1.5"L		3.0722	
Secondary Capillary Pump				
- 1.4 micron wick	0.43"ODx4mmIDx1.36"Lx0.40porosity			1.3922
- vapor grooves		0.5320		
Main Vapor Line	3/32"ODx0.082"IDx4.5mL	15.3319		
Additional Vapor Line	3/32"ODx0.082"IDx5.595"L	0.4842		
Liquid Line	1/16"ODx0.051"IDx4.5mL			5.9308
2nd Pump Line (Vapor)	1/16"ODx0.051"IDx4.5mL	5.9308		
Condenser Line	1/8"ODx0.093"IDx26.27"L		4.5407	
2nd Condenser Line	1/4"ODx0.194"IDx6"L		2.9063	
Swing Volume			60.000	
Expansion Reservoir Line	3/32"ODx0.082"IDx40"L	1.9630		

Flexible N2-ALHP for Across-Gimbal Cryocooling



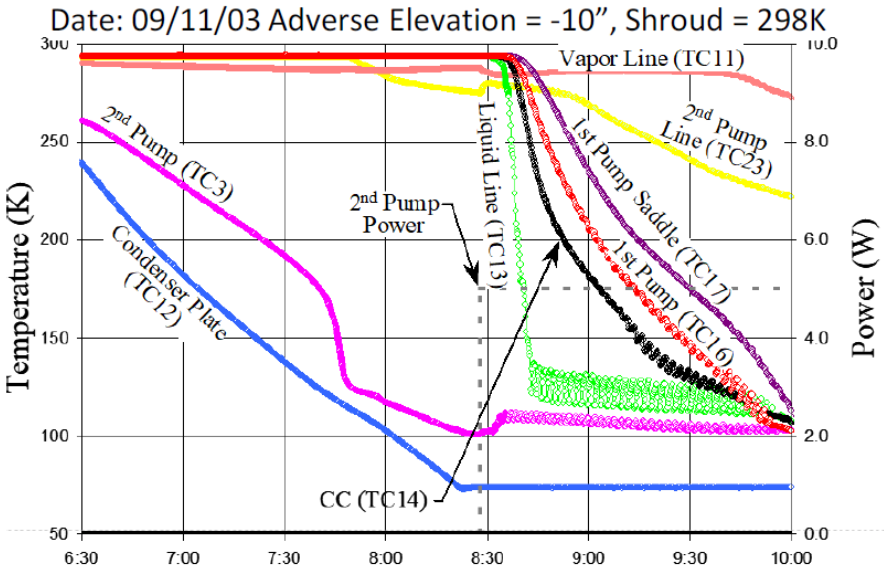


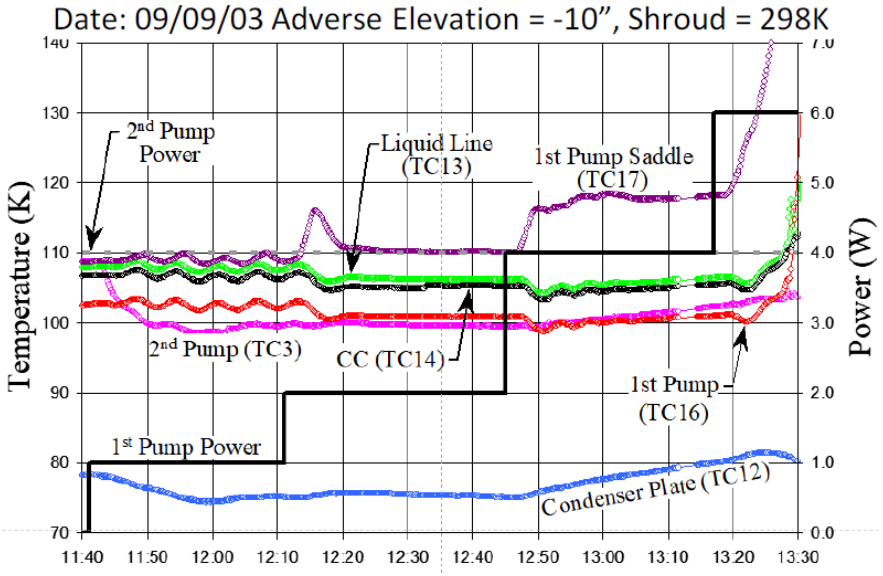


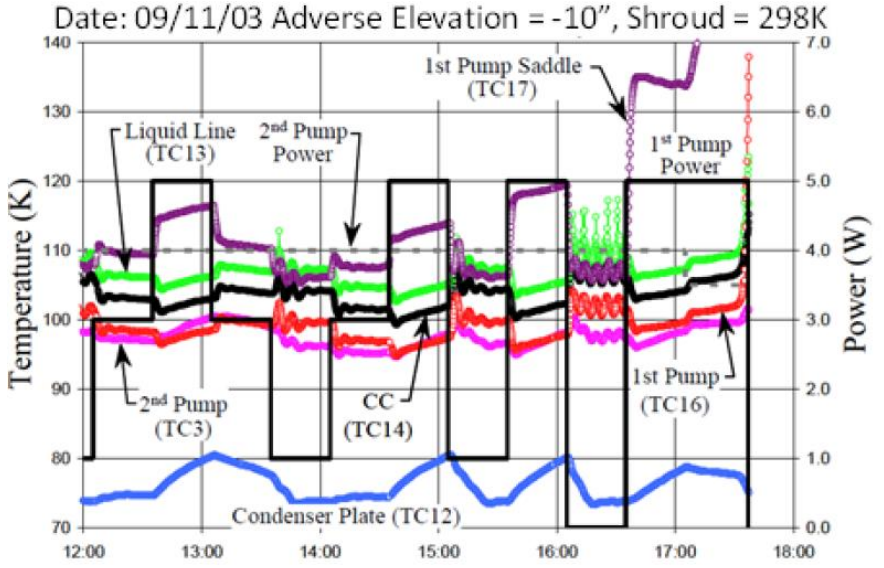


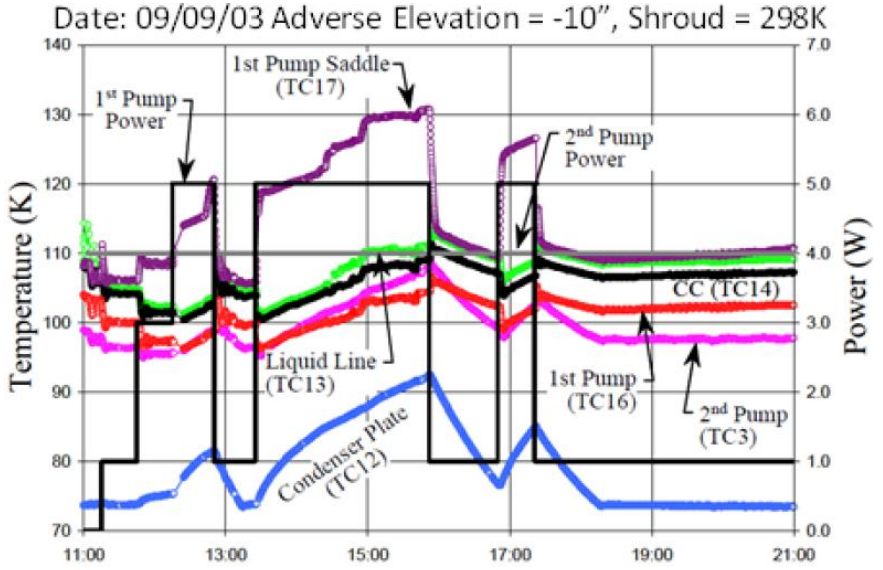
- *1/16” azimuth coil failed @256,417 full rotations*
- *3/32” azimuth coil failed @310,000 full rotations*

Flexible N2-ALHP for Across-Gimbal Cryocooling

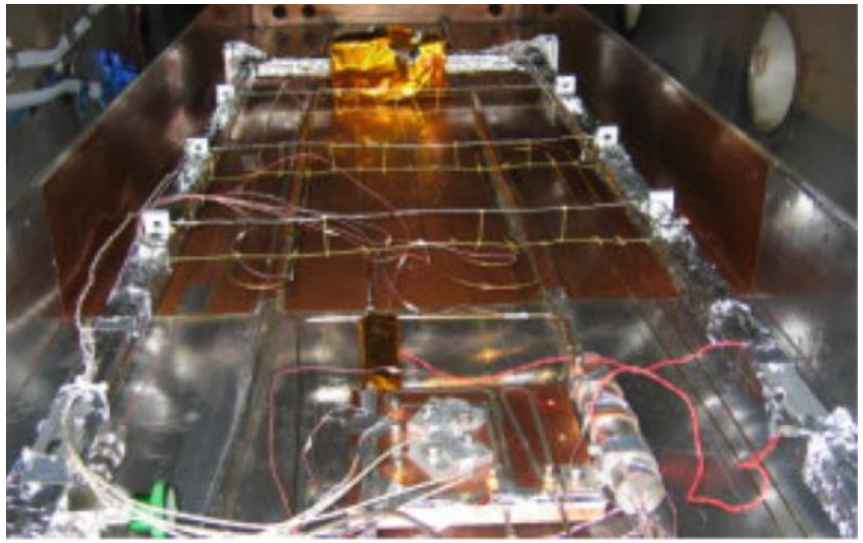








H2-ALHP Proof-of-Concept Demonstration



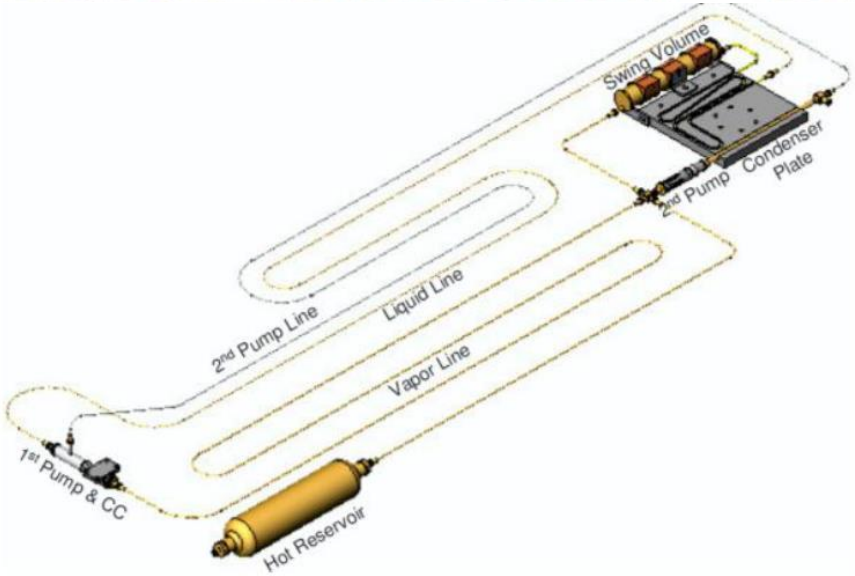
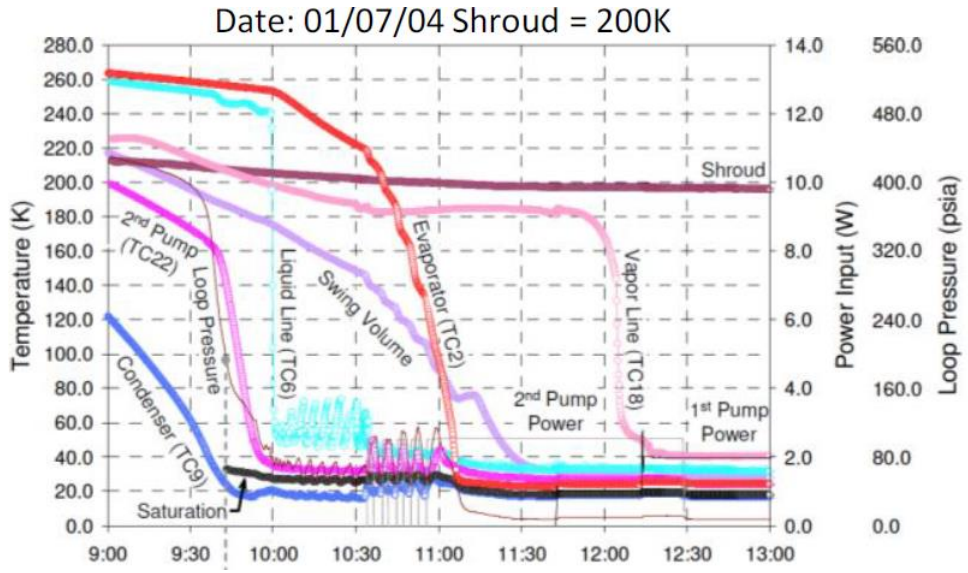
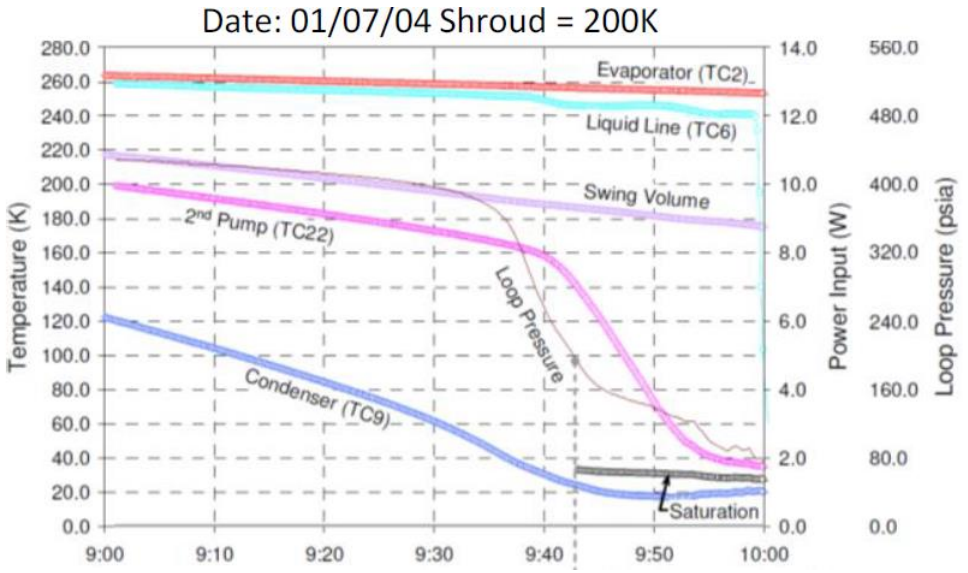


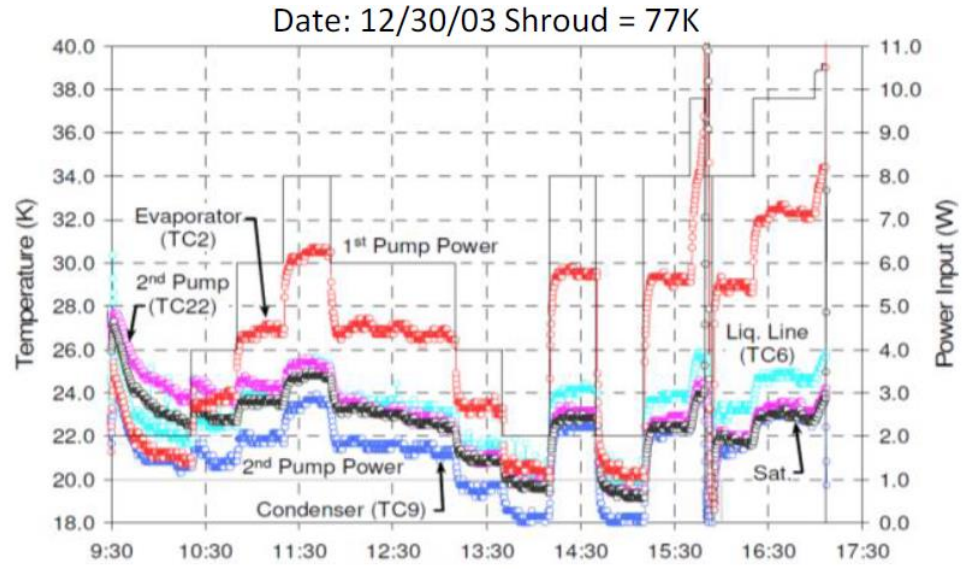
Table 2. Volume Breakdown of H2-ALHP Components

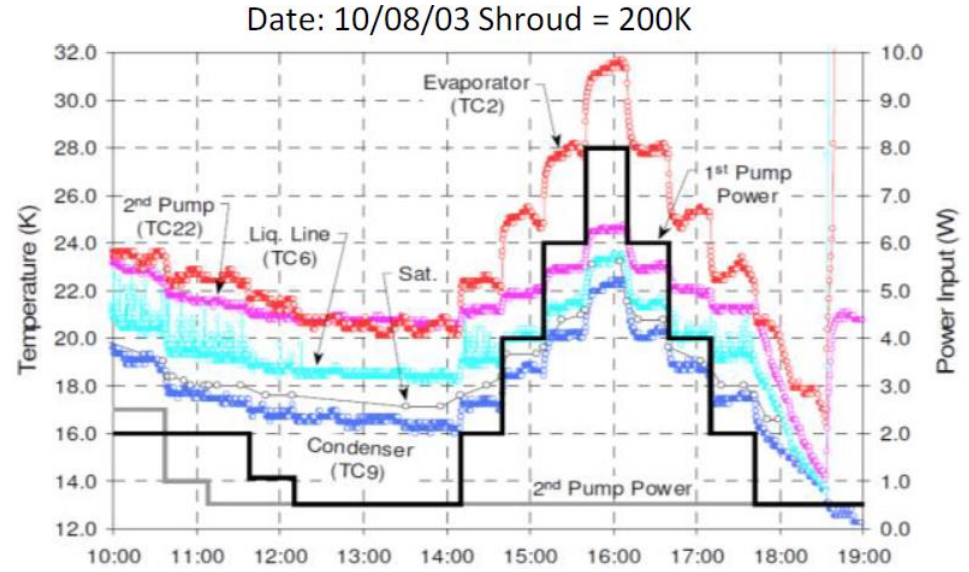
Components	Description	Vapor (cc)	Volume 2-ϕ (cc)	Liquid (cc)
Primary Capillary Pump				
- 1.89 micron wick	0.43"ODx4mmIDx1.36"Lx0.40porosity			1.2760
- vapor grooves		0.5320		
- reservoir	0.23"ODxTBD"L		6.0000	
Secondary Capillary Pump				
- 2.01 micron wick	0.43"ODx4mmIDx1.36"Lx0.40porosity			1.2760
- vapor grooves		0.5660		
- reservoir	0.23"ODxTBD"L		1.8880	
Main Vapor Line	3/32"ODx0.082"IDx2.5mL	8.4660		
Additional Vapor Line	1/16"ODx0.082"IDx5.595"L	0.4810		
Liquid Line	1/16"ODx0.051"IDx2.5mL			3.2310
Additional Liquid Line	1/16"ODx0.051"IDx2.5mL	3.2310		
Condenser Line	1/8"ODx0.093"IDx26.27"L		2.9240	
Additional Condenser Line	1/4"ODx0.194"IDx6"L		2.9060	
Swing Volume			60.000	
Expansion Reservoir Line	3/32"ODx0.082"IDx40"L	3.4410		

H2-ALHP Proof-of-Concept Demonstration

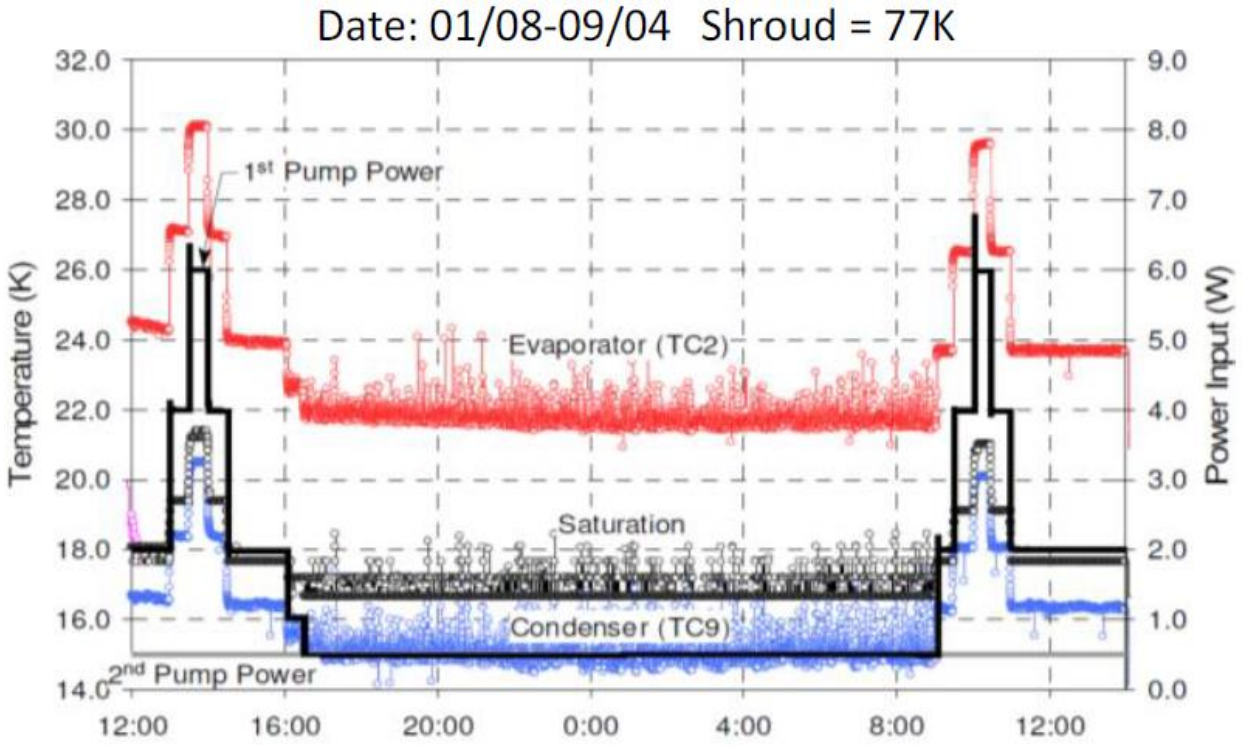


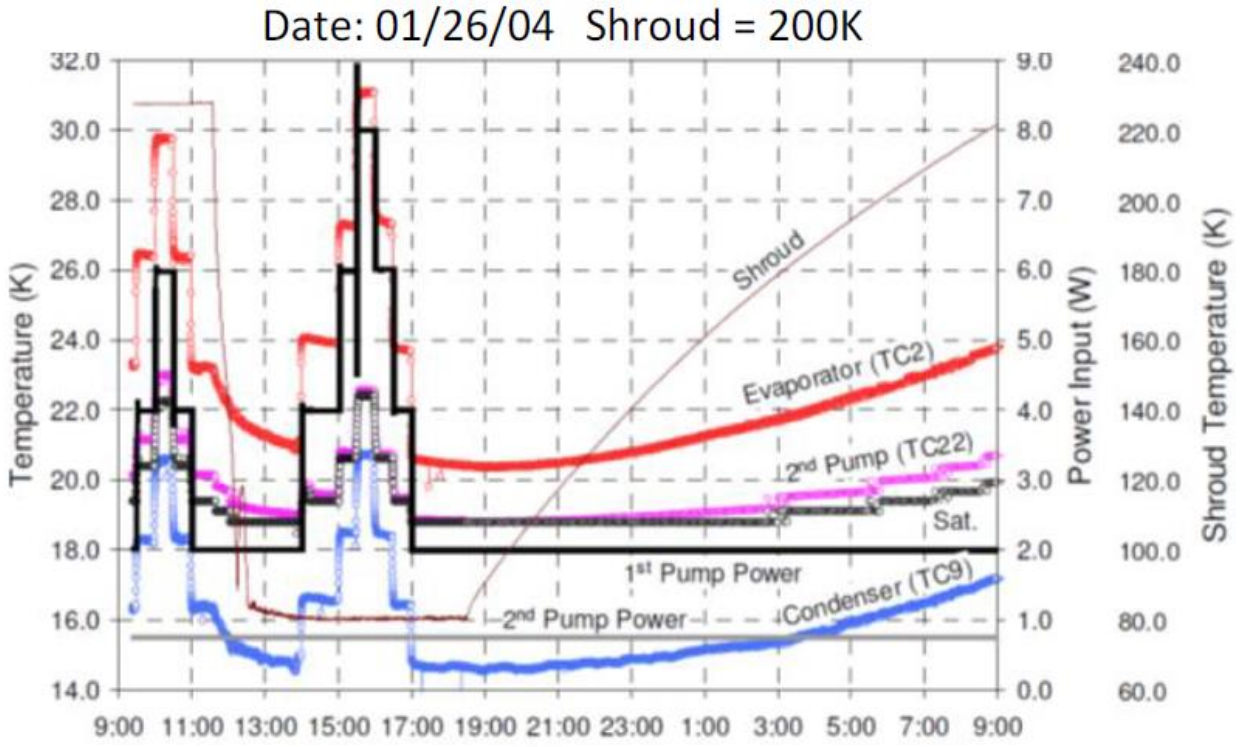






H2-ALHP Proof-of-Concept Demonstration





Ne-LHP for Large-Area Cryocooling Demonstration

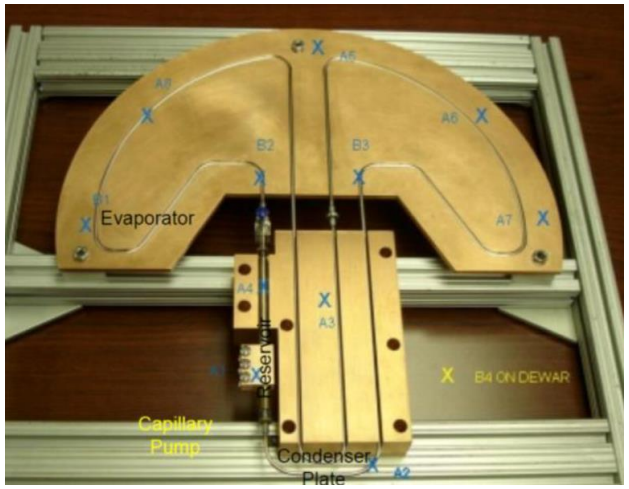
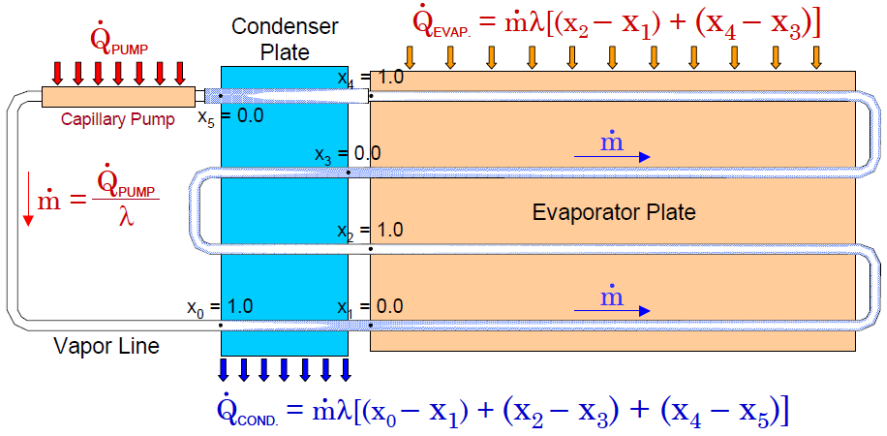
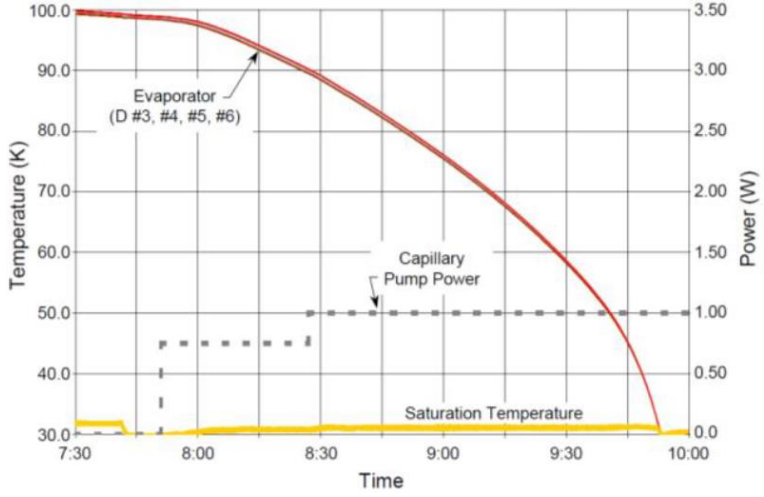
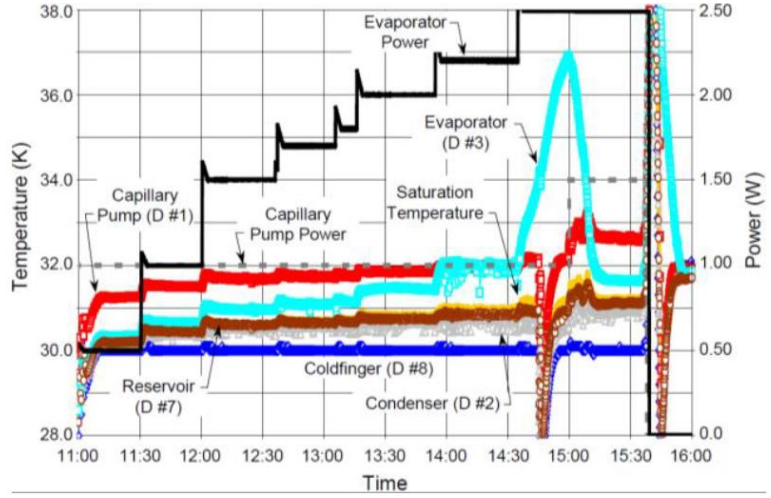


Table 3. Volume Breakdown of He-ALHP Components

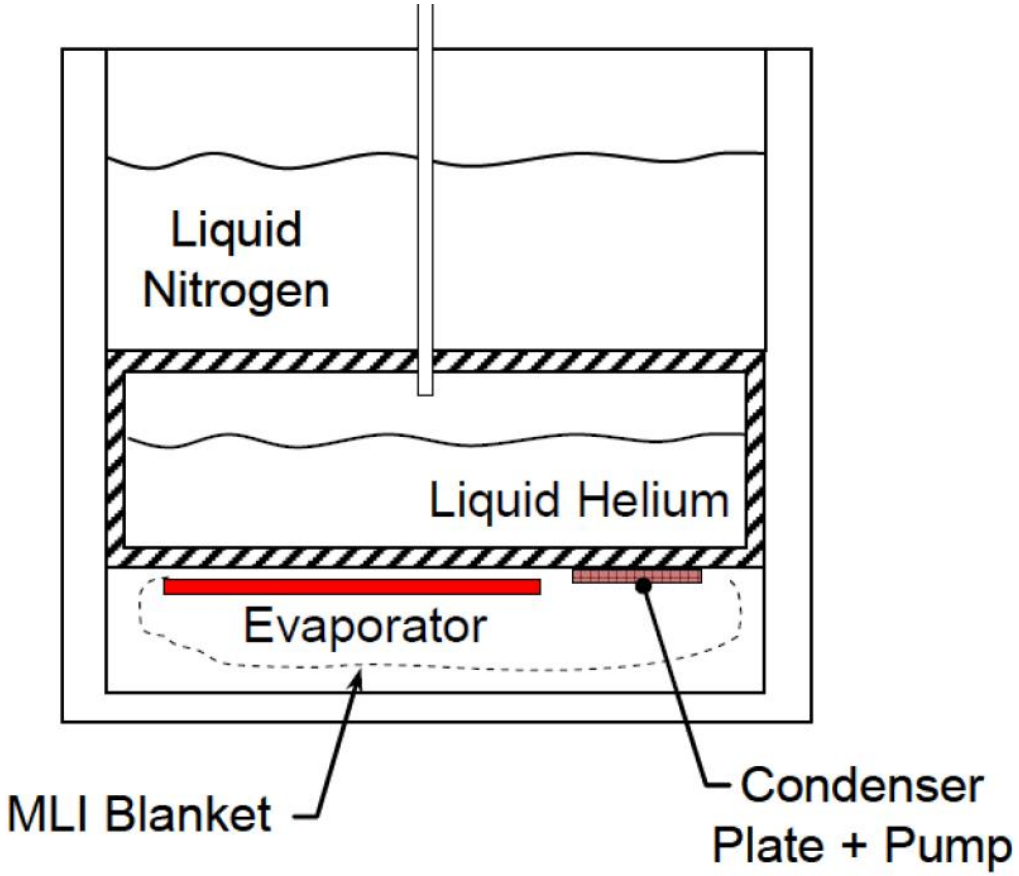
Components	Description	Volume Vapor (cc)	Volume 2Φ (cc)	Volume Liquid (cc)
Capillary Pump				
- 1.25micron wick	0.21"ODx0.078"IDx2"Lx0.40%			0.3914
- reservoir	0.25"ODx0.02"wallx2.5"L		1.1352	
Vapor Line	3/32"ODx0.016"Wx12"L	0.4908		
Evaporator Line	3/32"ODx0.016"Wx40"L			3.5000
Condenser	3/32"ODx0.016"Wx13"L		0.7361	



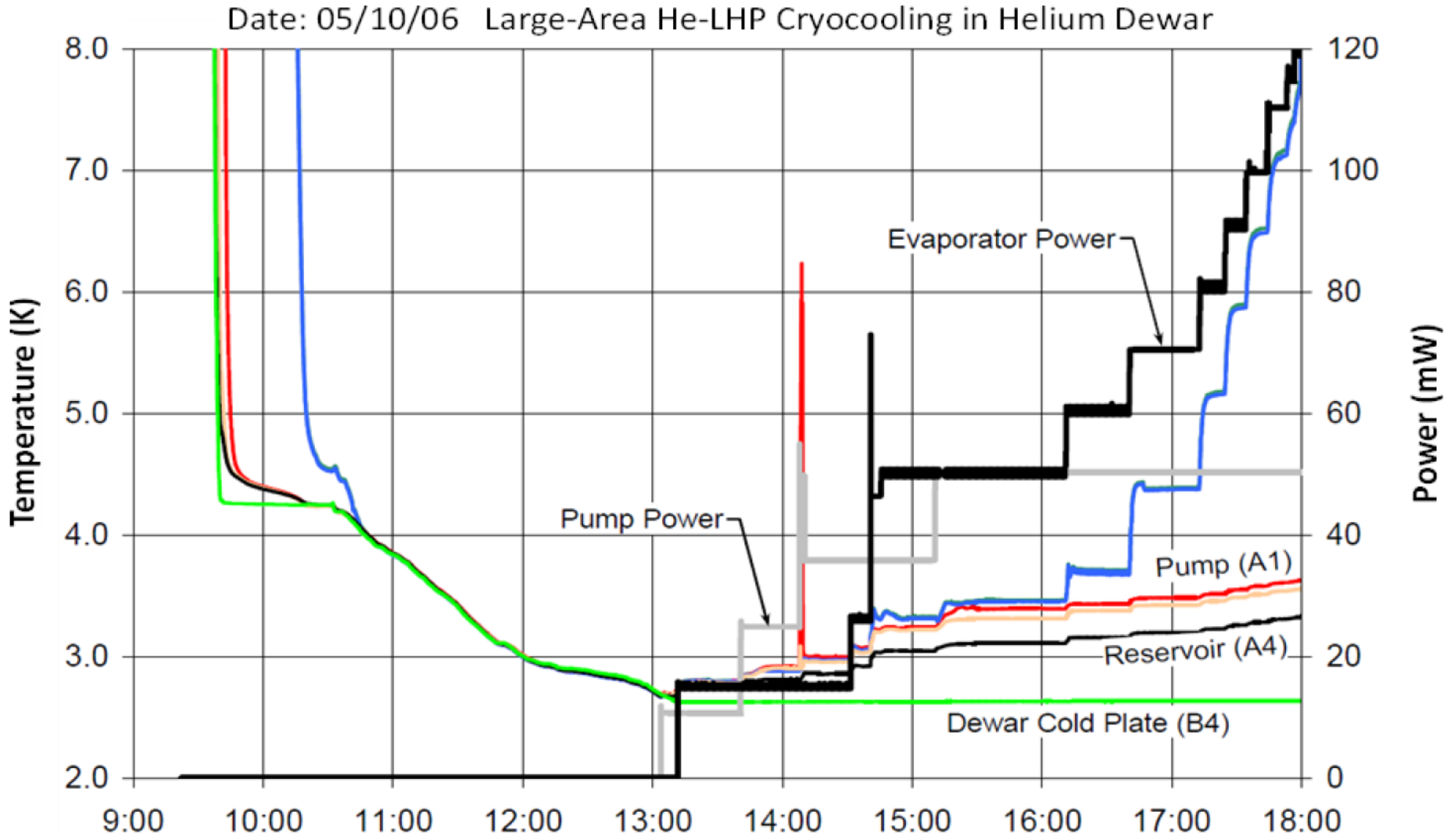




He-LHP for Large-Area Cryocooling Demonstration



He-LHP for Large-Area Cryocooling Demonstration



Summary

- Cryogenic Cooling Needs for Next-Generation Infrared Space Telescopes
  - temperature range: 2K – 150K
  - reliability and long life in addition to Size, Weight and Power (SWaP) optimum
- Cryogenic Advanced Loop Heat Pipe Technology Development for GSFC
  - leveraged proven room-temperature LHP technology in terms of theoretical understanding, computational expertise, hardware design & fabrication
  - incorporate innovative ideas to overcome unique operational challenges
- Proof-of-Concept Performance Demonstration
  - designed/constructed *all-stainless-steel* C-ALHP testbed and carried out nominal testing in thermal vacuum chamber for performance evaluation
  - demonstrated cryogenic operations with (i) Nitrogen for cryocooling transport across 2-axis gimbal, (ii) Hydrogen/Neon, and (iii) Helium
  - every cryocooling demonstration project was a unqualified success.