Next Generation of High-Heat-Flux Heat Pipes for Space Thermal Control Applications

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Presentation Outline

- Motivation
- Background
- Hybrid Wick Heat Pipe Concept
- High-Heat-Flux CCHPs
- Conclusion
- Acknowledgment

Motivation

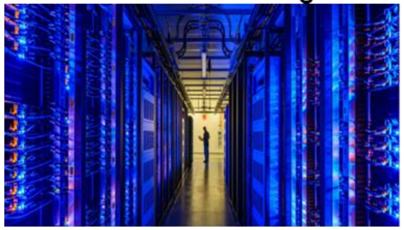
- **The electronic design community is facing a new level of thermal challenges for the next-generation electronic systems.**
  - **It is typical to have localized high heat flux components located within the system in direct contact to other components, which are sensitive to high temperature.**
- **Examples of applications demanding high heat flux cooling solutions:**
  - **Medical**
  - **Automotive**
  - **Computer**
  - **LED**
  - **Military**
  - **Space**

Medical
X-ray Imaging System

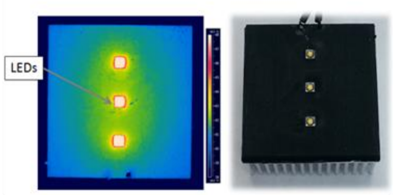
Space
Satellite Applications

Automotive
Power Electronic & Battery Cooling

Computer
Data Center Cooling



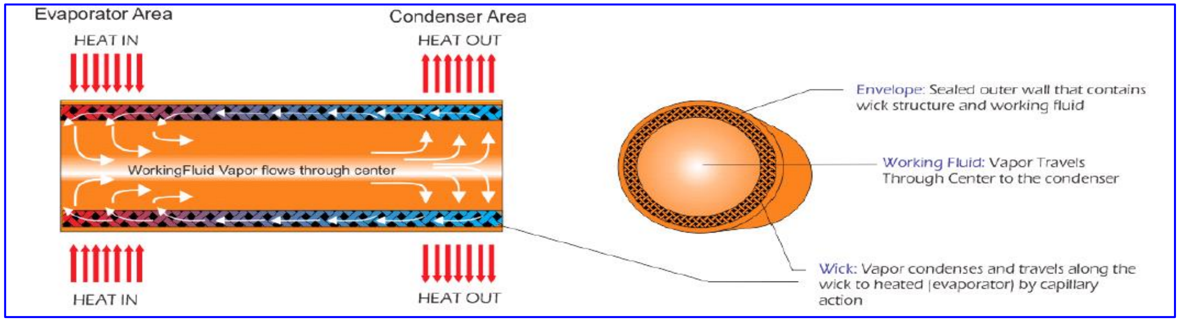
LED Thermal Management
HP Embedded Circuit Board during LED Operation

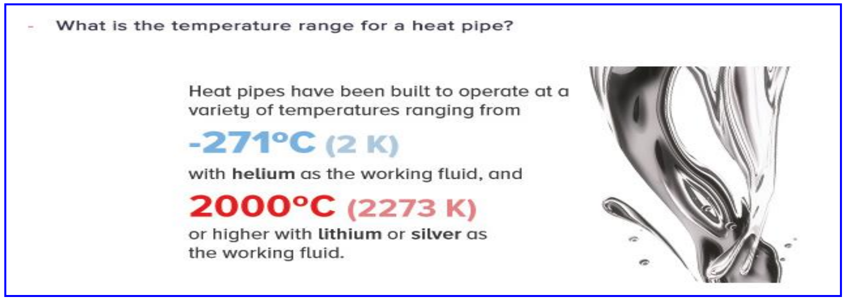


Military
RADAR Thermal Management

Background: Heat Pipes

- Passive two-phase heat transfer device operating in a closed system
- Working fluid vaporizes utilizing the latent heat of vaporization
- Vapor flows to cooler end due to the slight pressure difference
- Vapor condenses and returns to evaporator by gravity or capillary force
- Typically a 2-5˚C ΔT across the length of the pipe





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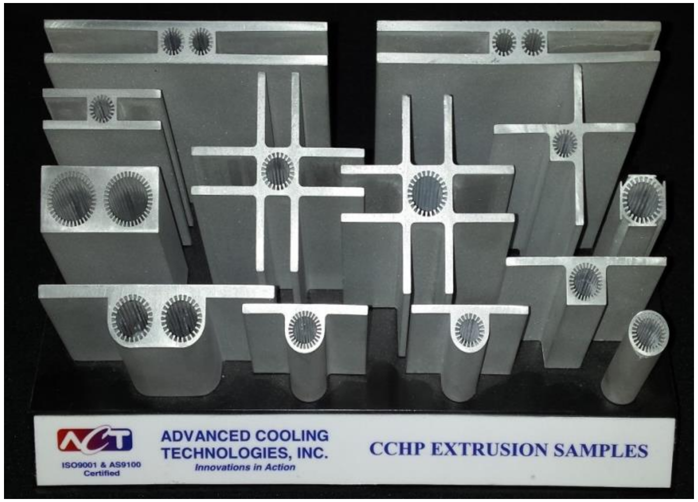
Background – Axial Grooved CCHPs

- **Standard for spacecraft HPs**
  - Very high permeability.
  - Allows for very long heat pipes (up to ≈3.5 m).
- **Only suitable for zero-g/ gravity-aided operation**
  - Low capillary pumping capability.
  - 0.1" against earth gravity.
- **Drawbacks:**
  - Low heat flux limitation in the evaporator
  - No pumping capability against gravity on planetary surfaces



ACT'S CCHP SPACE FLIGHT HOURS: 25,911,190.6

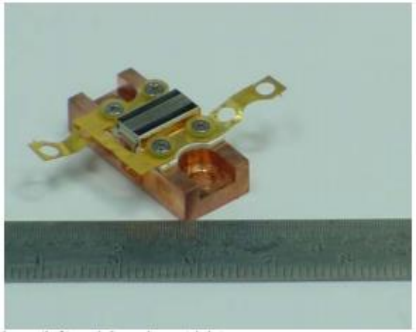
ACT's solution – Hybrid wick CCHP

Hybrid Wick Heat Pipe Concept

- **Future spacecraft and instruments for NASA's Science Mission Directorate:**
  - **Can involve high power electronics with heat fluxes approach ~ 50 W/cm^2.**
  - **High heat flux limitation for future high power electronics such as laser diodes.**

- **High heat flux (~ 50 W/cm^2) is a severe limitation for:**
  - **Standard grooved CCHPs.**
  - **Loop heat pipes (LHPs).**

- **ACT is developing a novel hybrid wick CCHP for:**
  - **Lunar and Martian landers and rovers.**
  - **Solving the high heat flux limitation for future highly integrated electronics.**

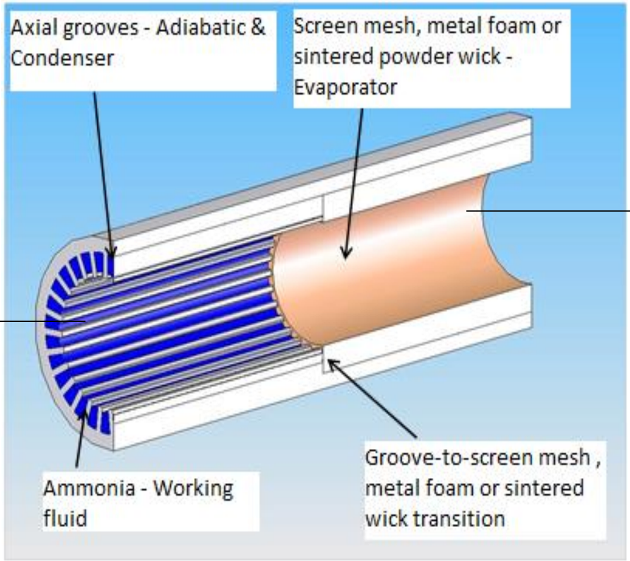


High power laser diode arrays (LDAs)

Hybrid Heat Pipes - Concept

- **Heat pipe with a hybrid wick that contains screen mesh, metal foam or sintered evaporator wicks for the evaporator region.**
  - **Can sustain high heat fluxes.**
- **The axial grooves in the adiabatic and condenser sections**
  - **Can transfer large amounts of power over long distances due to their high wick permeability and associated low liquid pressure drop.**

Adiabatic and Condenser sections:
Large pore size responsible for the:
- ✓ **high permeability.**
- ✓ **low pumping capability.**
- ✓ **Relatively low heat flux limitation.**

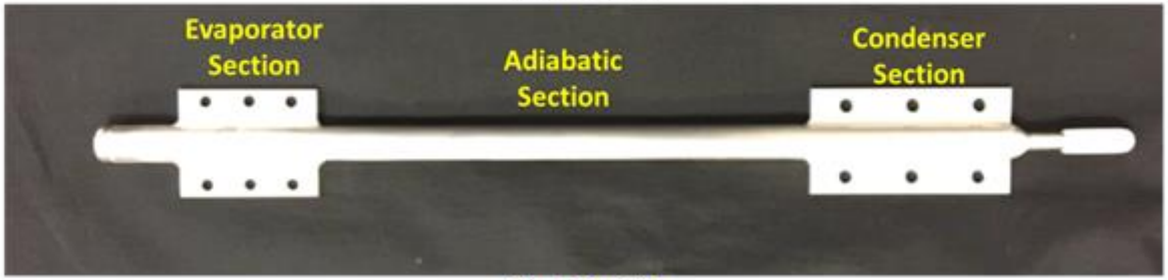


Evaporator section:
Small pore size responsible for the:
- ✓ **Low permeability.**
- ✓ **High pumping capability.**
- ✓ **Relatively high heat flux limitation.**
- ✓ **eliminate start-up problems.**

Hybrid High-Heat-Flux Heat Pipes Fabrication

- Two aluminum/ammonia hybrid high-heat-flux (HHF) heat pipes were designed and fabricated
- These heat pipes (bended (HHF1) and straight (HHF2)) represent the high heat flux design with sintered powder metal in the evaporator and axial grooves in the condenser and adiabatic sections.

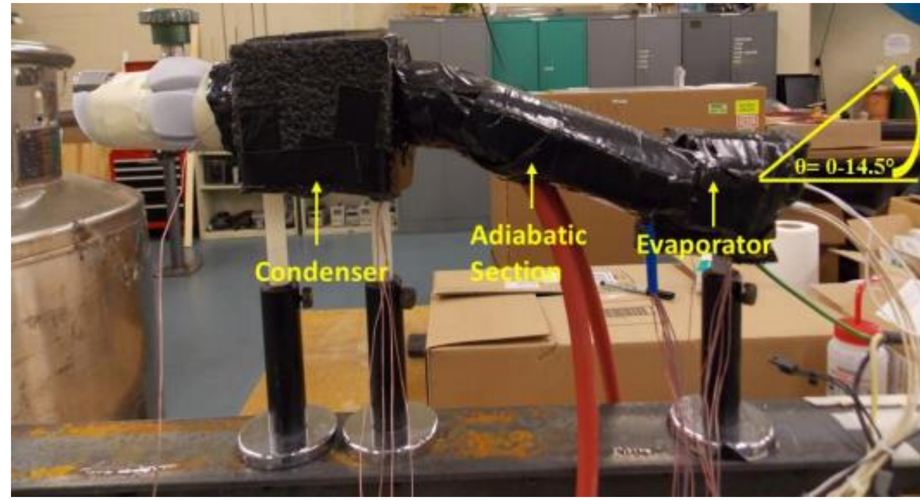
(a: HHF1)

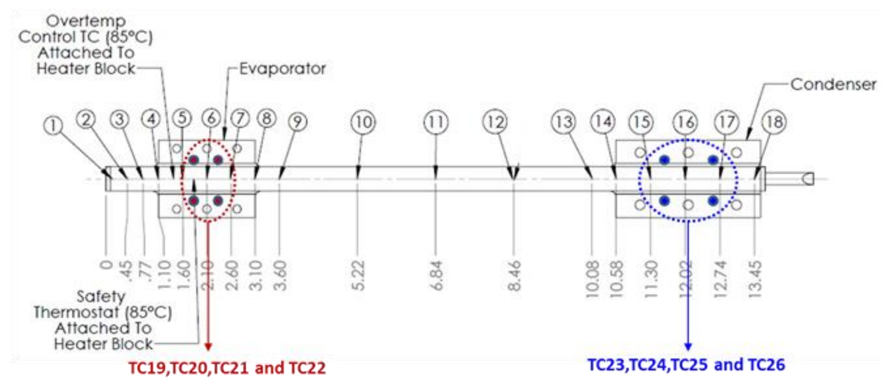


(b: HHF2)

Hybrid (HHF1) Heat Pipes Testing

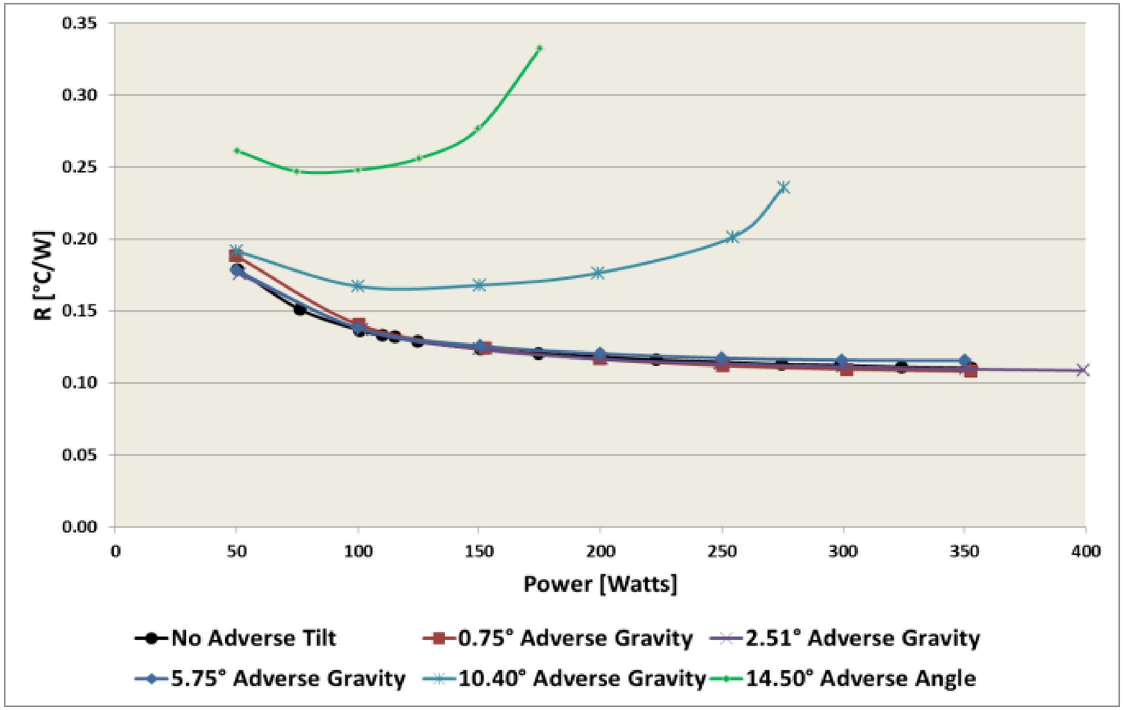
- Testing was performed between 0° - 14.5° adverse elevation between the evaporator and the condenser, with the evaporator above the condenser.
- An aluminum heater block with 2 (200 W) cartridge heaters is used as the heat input source.
- The condenser sink condition was established using an aluminum block connected with a Liquid Nitrogen (LN) source.
- The pipe was instrumented with type T thermocouples



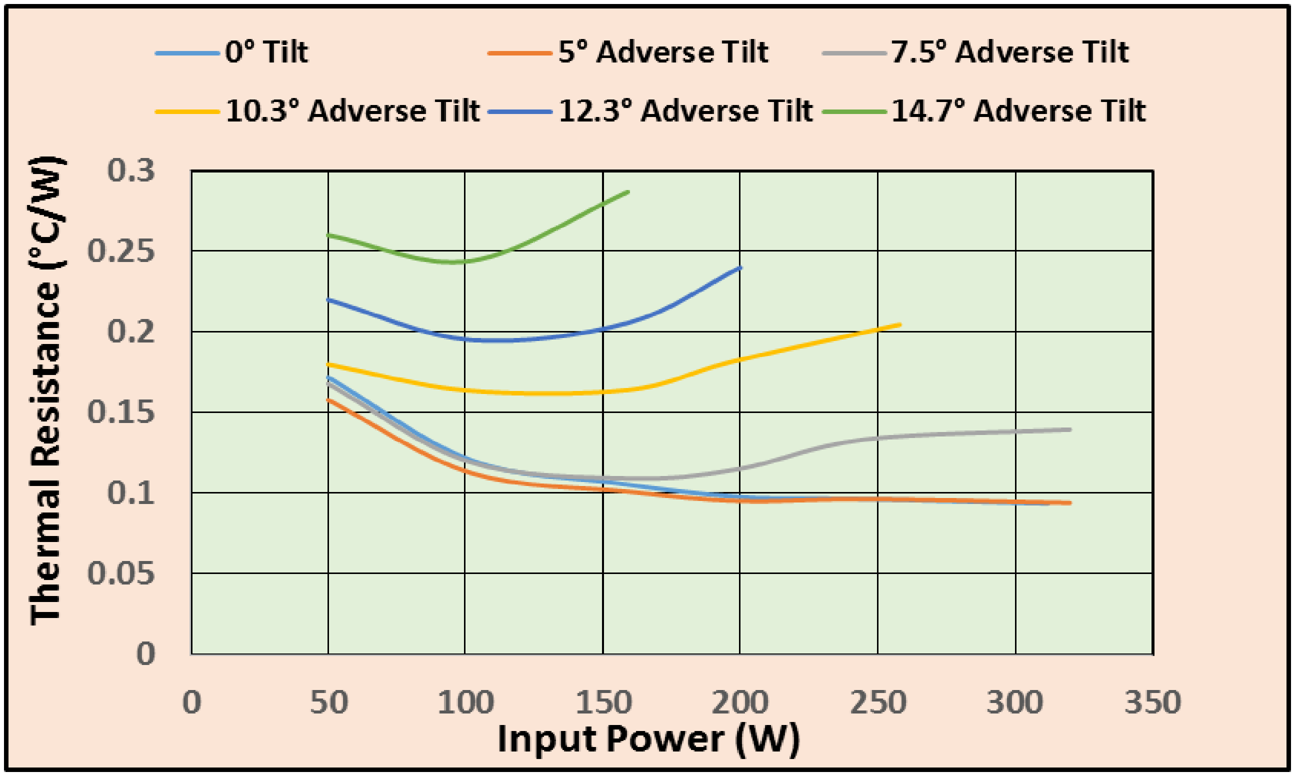


Hybrid (HHF1) Heat Pipes Testing Results

- The HHF1 pipe transported a heat load of ~ 350 W up to 8.2° adverse elevation respectively before complete dry-out.
- The thermal resistance as a function of power for the bended hybrid HHF1 heat pipe in horizontal positions (between 0.1° to 14.5° adverse elevation) is shown below:

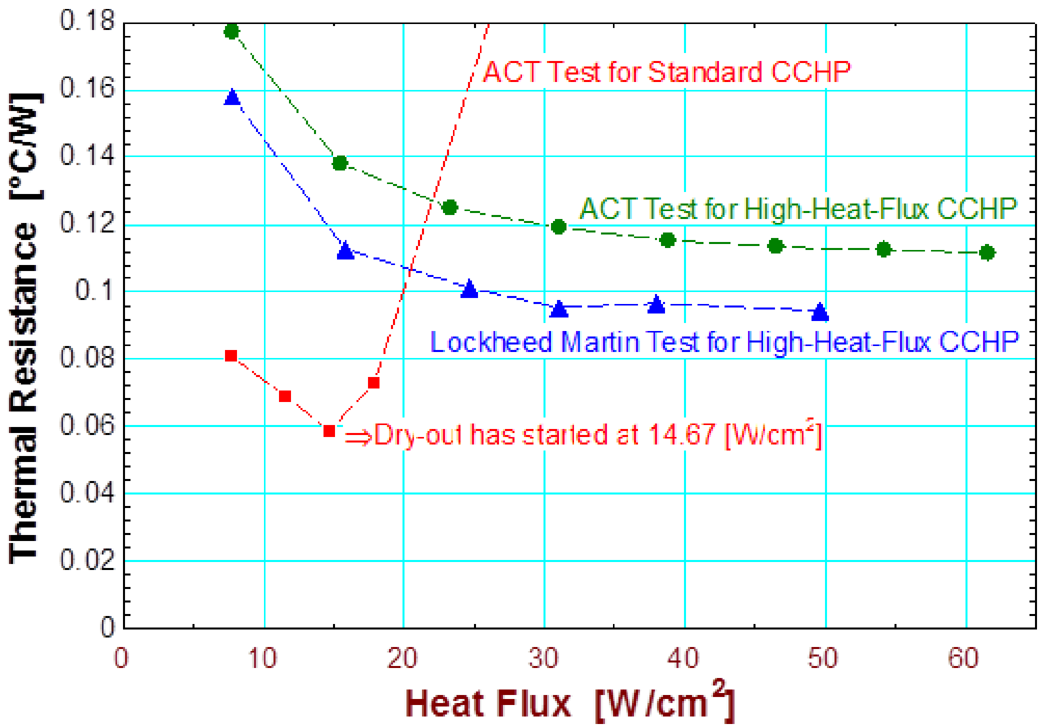


- The bended high-heat-flux (HHF1) hybrid heat pipe was shipped to Lockheed Martin Coherent Technologies, Inc. for validating the testing results.
- The testing results from Lockheed Martin is shown below:



Hybrid (HHF1) Heat Pipes Results

- **The high-heat-flux (HHF1) aluminum/ammonia CCHP transported a heat load of > 310 Watts with heat flux input of > 48 - 62 W/cm^2 and thermal resistance < 0.12 ºC/W.**
- **This demonstrates an improvement in heat flux capability of <u>more than 3 times</u> over the standard axial groove aluminum-ammonia CCHP design.**



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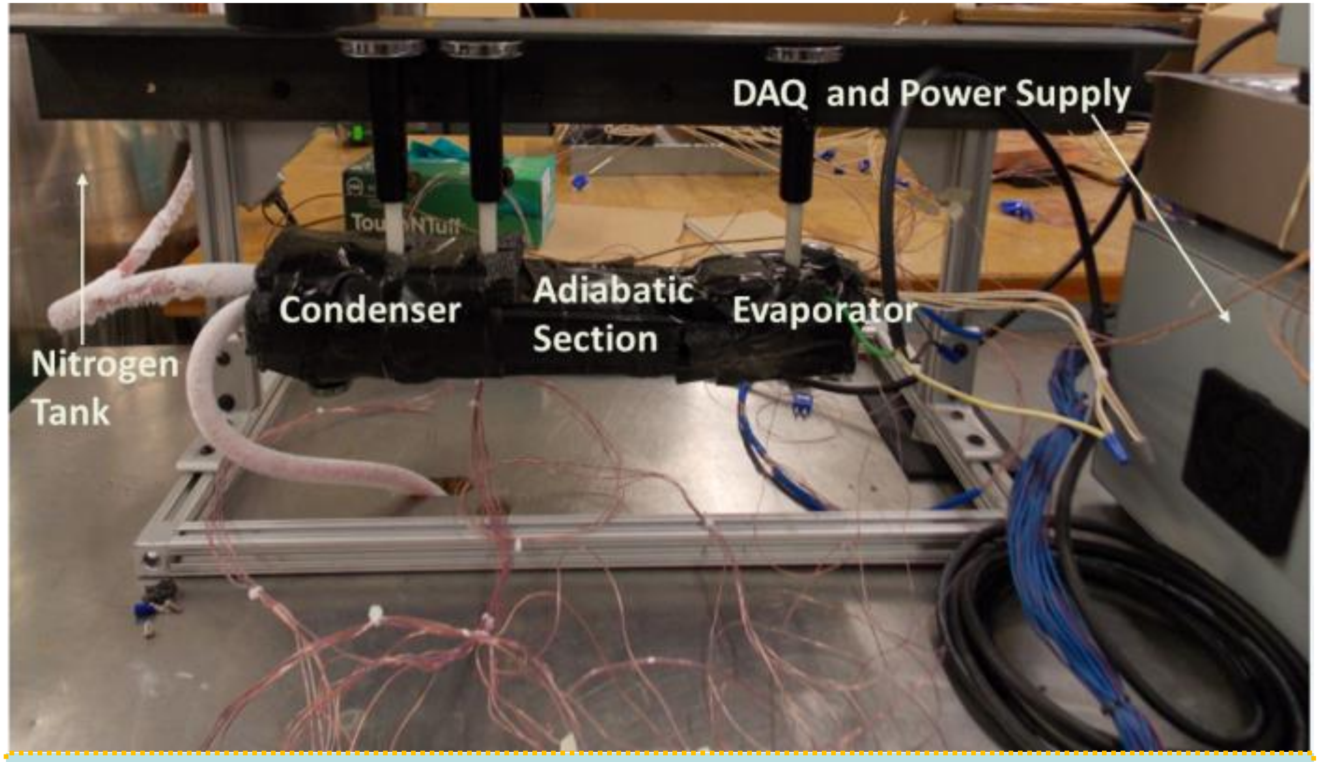
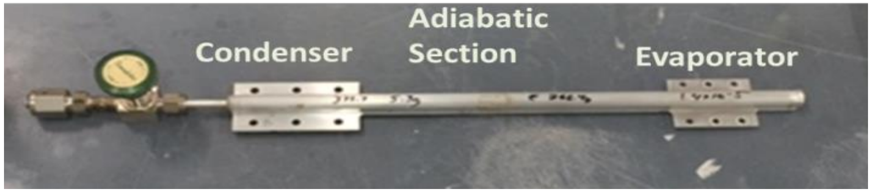
- **The hybrid HHF2 heat pipe was tested in horizontal non-inverted "standard orientation" positions (between 0.1" to 0.3" adverse elevation)**

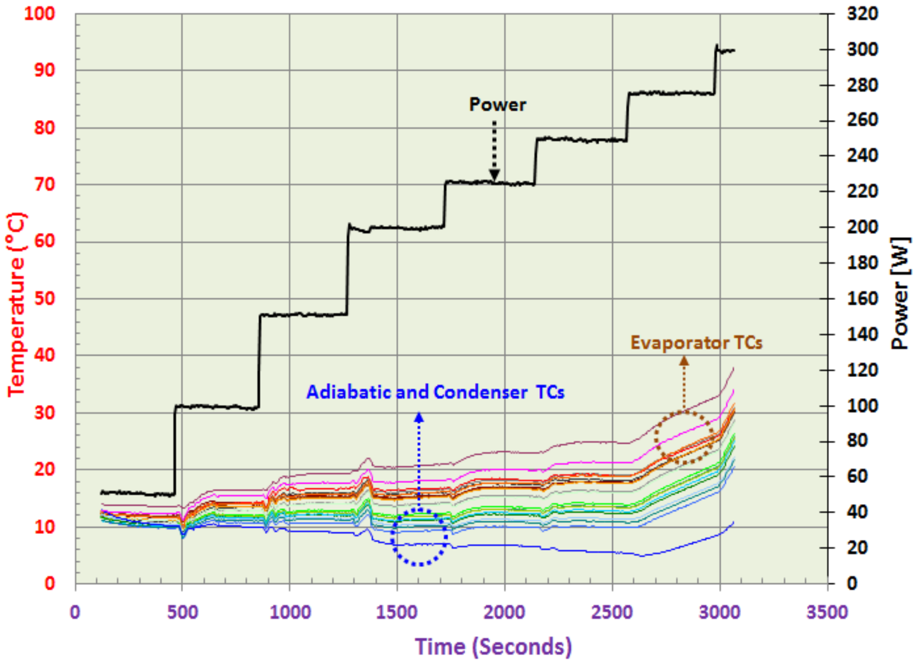


The second hybrid aluminum-nickel-ammonia high heat flux CCHP under performance test

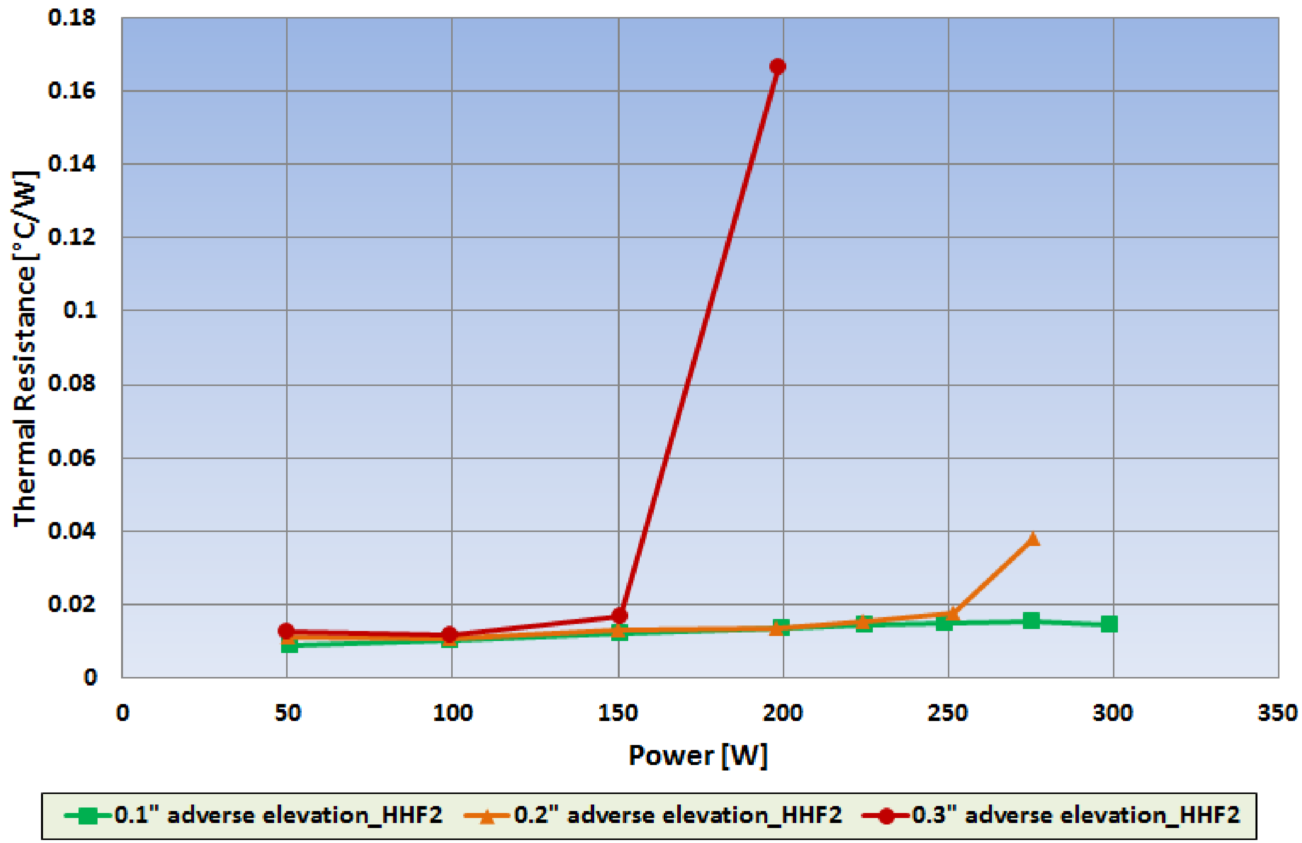
Hybrid Wick (HHF2)Heat Pipes-Results

- Successfully sintered a nickel powder metal wick to the desired requirements
- Successfully inserted a sintered nickel wick into a 0.5" OD aluminum extrusion
- Successfully tested the high heat flux (HHF) hybrid CCHPs
- The hybrid wick high heat flux aluminum/ammonia CCHP transported a heat load of 275 Watts with heat flux input of 54 W/cm^2 and R=0.015 ºC/W at 0.1 inch adverse elevation.
- This demonstrates an improvement in heat flux capability of more than 3 times over the standard axial groove CCHP design.
- The hybrid CCHP exceeds the 30 years life time (i.e. exceeds the 345 days operation at 75° C)





- **The thermal resistance as a function of power for the second hybrid heat pipe in horizontal positions (between 0.1” to 0.3” adverse elevation) is shown below:**



Conclusion

- **ACT develops new generation of high-heat-flux CCHPs based on hybrid wick technology.**
- **The 5 – 15 W/cm^2 heat density limitation of aluminum-ammonia grooved heat pipes has been a fundamental limitation in the current design for space applications.**
- **Two high-heat-flux hybrid CCHPs were developed and tested.**
- **The first bended hybrid CCHP (HHF1) transported a heat load of > 310 Watts with heat flux input of > 48 – 62 W/cm^2 and thermal resistance < 0.12 ºC/W and the results were validated by Lockheed Martin.**

Conclusion

- The second hybrid CCHP (HHF2) transported a heat load of 275 Watts with heat flux input of 54 W/cm^2 and with a thermal resistance of 0.015 ºC/W at 0.1 inch adverse elevation.
- This demonstrates an improvement in heat flux capability of more than 3 times over the standard axial groove aluminum-ammonia CCHP design.
- The results show that the heat pipe performs efficiently, consistently and reliably and can adapt to many high heat flux applications.

Acknowledgements

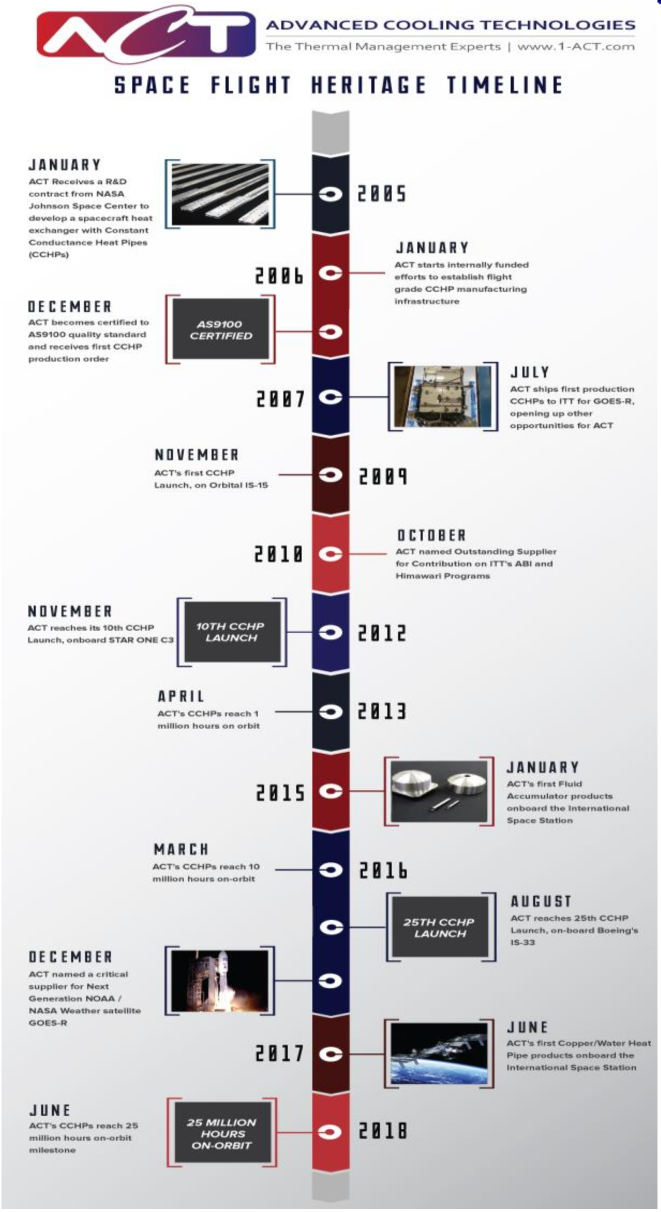
- The hybrid aluminum-ammonia CCHPs work was sponsored by NASA Marshall Space Flight Center under Contract No. NNX15CM03C.

- Dr. Jeffery Farmer is the contract technical monitor.

- Joel Wells, Chris Jarmoski, and Corey Wagner from ACT were the laboratory technicians responsible for the fabrication and testing of the heat pipes.

Questions?

Thank you for your attention!



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