



ADVANCED COOLING TECHNOLOGIES

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Qualifying Hybrid Variable Conductance Heat Pipes (VCHPs) and Copper-Water Heat Pipes in Microgravity

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Presentation Outline

- Motivation
- Background
- Hybrid Wick Heat Pipes
- ISS Flight APTx Experiment
- Conclusion

Motivation

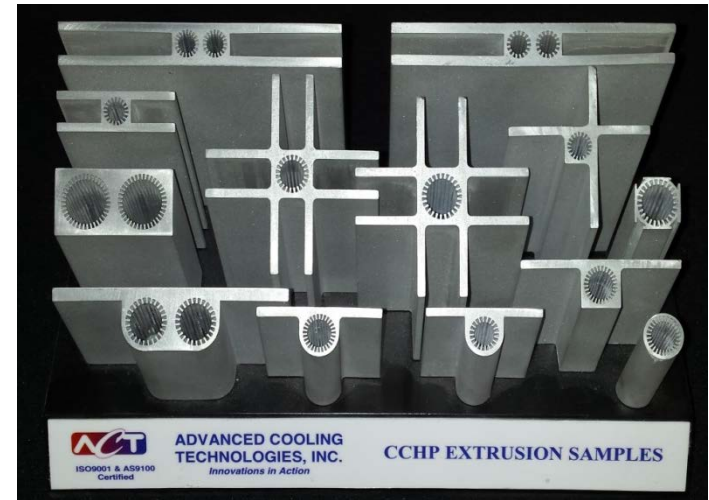
- Next generation of polar rovers and equatorial landers is the immediate NASA application.
- Planetary surface applications require against gravity operation in the evaporator:
 - The traditional grooves do not have the pumping capability.
 - Dissipate the heat flux generated by these electronics.
- ACT is proposing a novel hybrid wick CCHP for:
 - Lunar and Martian landers and rovers.
 - Solving the high heat flux limitation for future highly integrated electronics.
 - Vertical startup



NASA's RP polar rover design toward 2020 Launch

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: 23,268,268.6

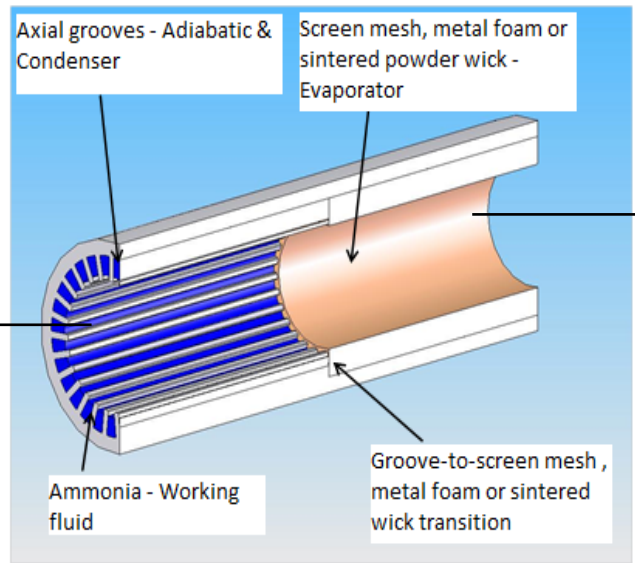
ACT's solution – Hybrid wick CCHP

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.

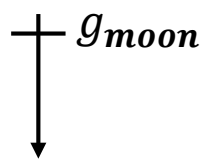


Evaporator section:
Small pore size responsible for the:

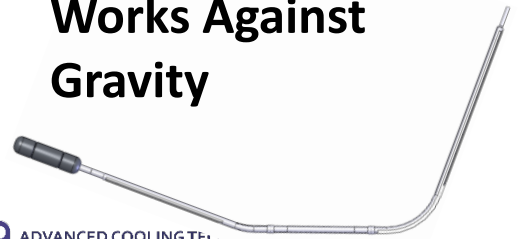
- Low permeability.
- High pumping capability.
- Relatively high heat flux limitation.
- eliminate start-up problems.

Hybrid Wick Heat Pipes Applications

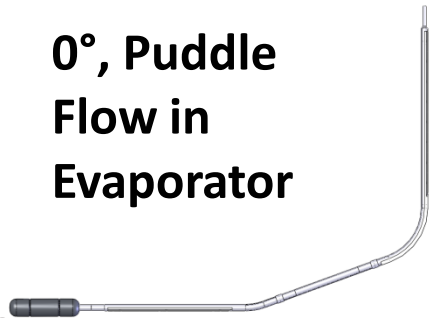
- Two related applications can benefit from using hybrid wicks:
 - For Planetary Surface:
 - Operation against gravity of VCHPs for Lunar Landers and Rovers
 - Sintered wick in evaporator to accommodate tilt and grooves in condenser and adiabatic sections.
 - Test against gravity 4.2° (only the evaporator) while the rest of the pipe is gravity aided.
 - Test 0.1" against gravity (for operation in space).
 - For Spacecraft:
 - High Heat Flux in evaporator
 - Sintered wick in evaporator and grooves in condenser and adiabatic sections.
 - Test 0.1" against gravity.



-14°, Evaporator Works Against Gravity



0°, Puddle Flow in Evaporator



+14°, Evaporator Gravity Aided



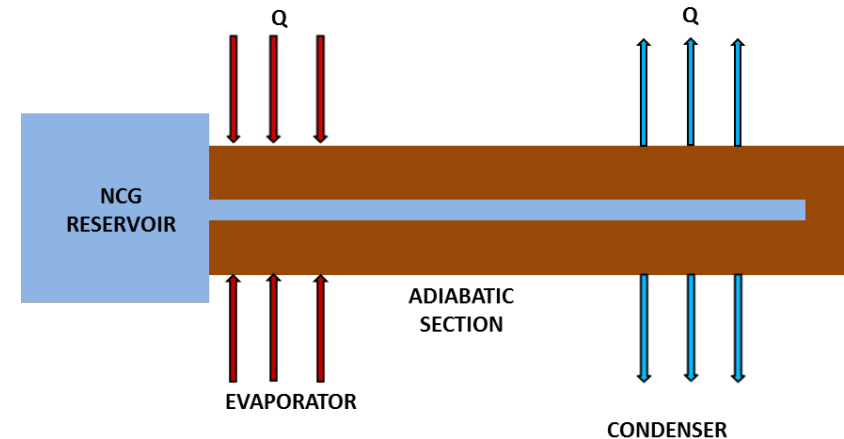
VCHPs for Variable Thermal Links

- Variable Conductance Heat Pipes (VCHPs) can be used for variable thermal links
 - Maintain evaporator temperature range in a fairly broad temperature range with large variations in sink temperature
 - Transmit heat readily during hot sink conditions
 - Minimize heat transmission during cold sink conditions
- Variable Thermal Link useful when
 - Variable system loads resulting from intermittent use
 - Large changes in environment temperature
 - Lunar surface temperature range: -140 °C to 120 °C
 - Limited electrical power
 - Lunar Application: 1 W = 5 kg of energy storage and generation
- Applications that can benefit from using VCHPs as variable thermal links include
 - Lunar and Martian Landers and Rovers
 - Research Balloons (fly near Poles in winter)
 - Lunar and Space Fission Reactors



Hybrid Wick Warm Reservoir VCHP

- In contrast to the standard cold VCHP, the hybrid wick VCHP has a warm reservoir located adjacent to the evaporator.
- The warm reservoir is mainly follow the payload (i.e. evaporator) temperature.
- The warm reservoir provided tighter temperature control than standard cold reservoir.
 - Although it is slightly more complicated.
- Based on this concept, the 1-2 Watts required keeping the reservoir at the correct temperature will be eliminated.
 - This is a necessity for Lunar applications, where it is estimated that supplying 1 W over the 14-day long Lunar night requires 5 kg of solar cells, batteries, etc.



Copper-Water Heat Pipes

■ Benefits:

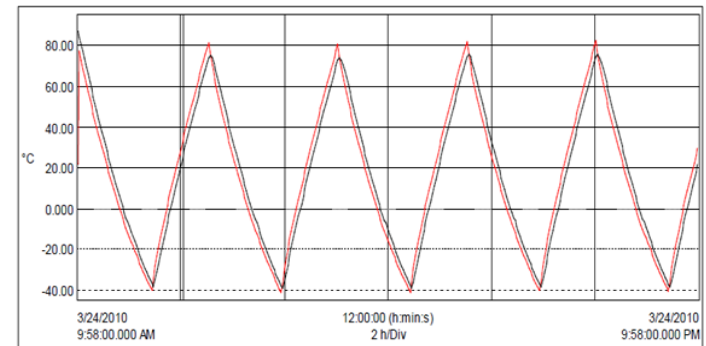
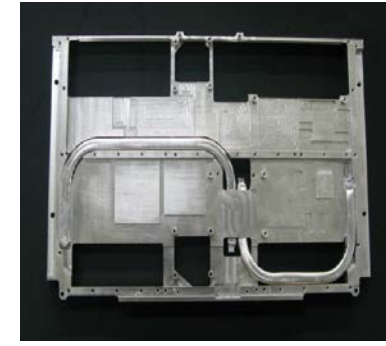
- Reliable, proven
- High performance
- Ground testable
- Easy integration
- Cost effective

■ ACT Capabilities

- Proven prototype & volume
- Demonstrated capacity > 250,000 per year

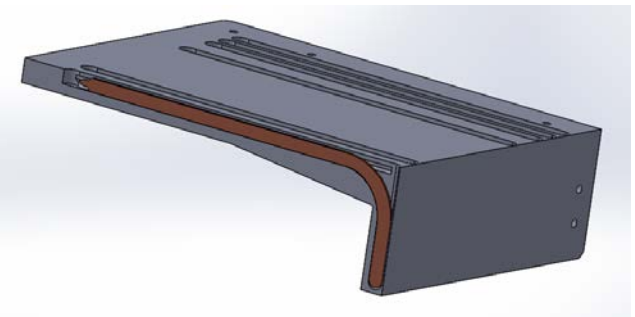
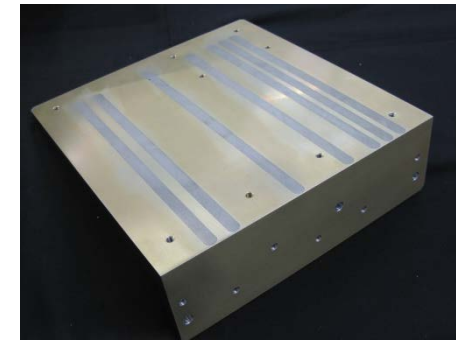
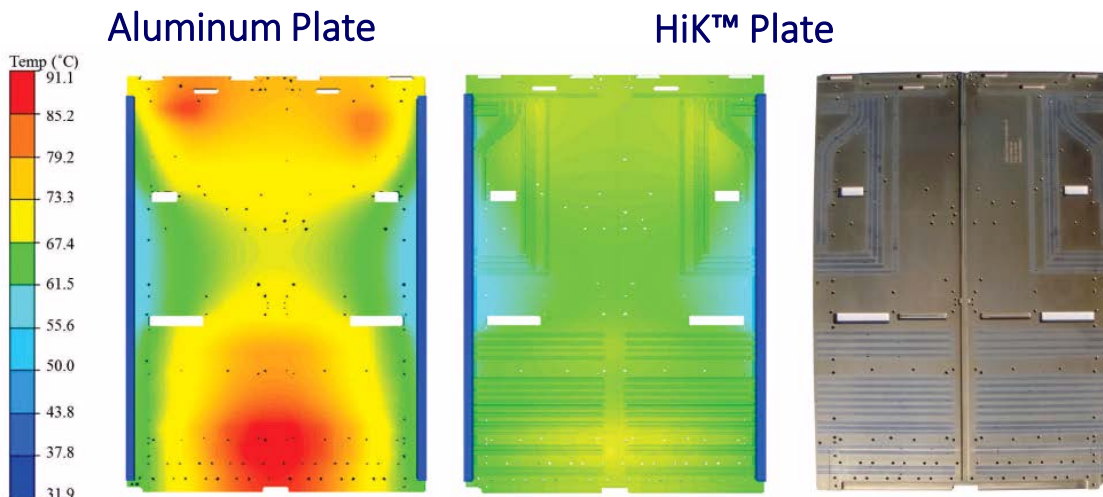
■ Qualification / Space Readiness

- Freeze/Thaw tolerant
- Shock/Vibe tolerant
- **Flight hardware tested on the ISS**



Embedded Heat Pipe Plates (HiK™)

- HiK™ plates have copper/water or copper/methanol heat pipes
 - Flatten, solder in machined slots
 - Can withstand thousands of freeze/thaw cycles
 - Operate up to 12 inches against gravity (if water is used)
 - Effective thermal conductivity of 500 – 1200 W/m K for terrestrial applications, up to 2500 W/m K for spacecraft
- Identical dimensions, 22°C reduction in peak temperature measured



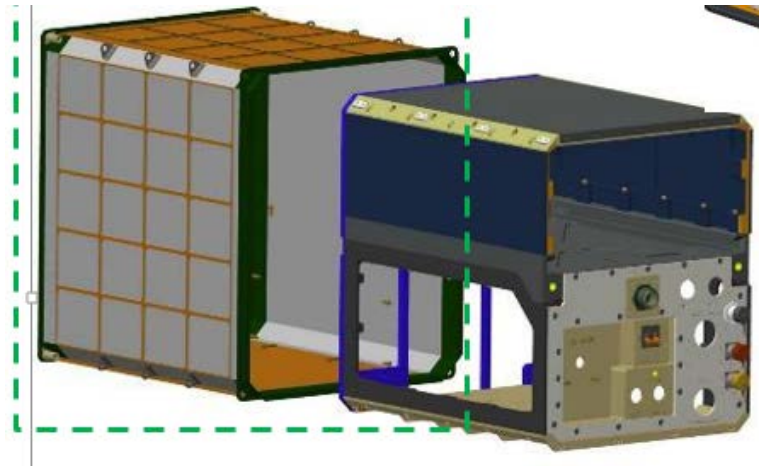
The Advanced Passive Thermal eXperiment (APT_x) on board the ISS

- NASA Marshall and NASA Johnson worked on an ISS flight experiment with components supplied by ACT.
- Experimental configuration – 2 experiments
 - Payload #1: VCHP with HiK™ plate – designed so that heat is delivered to the VCHP, whether or not the HiK™ plate works.
 - Payload #2: Separate HiK™ plate
- Envelope/Working Fluid Selection
 - Monel-Copper/water for VCHP
 - HiK™ plates with embedded copper/water heat pipes



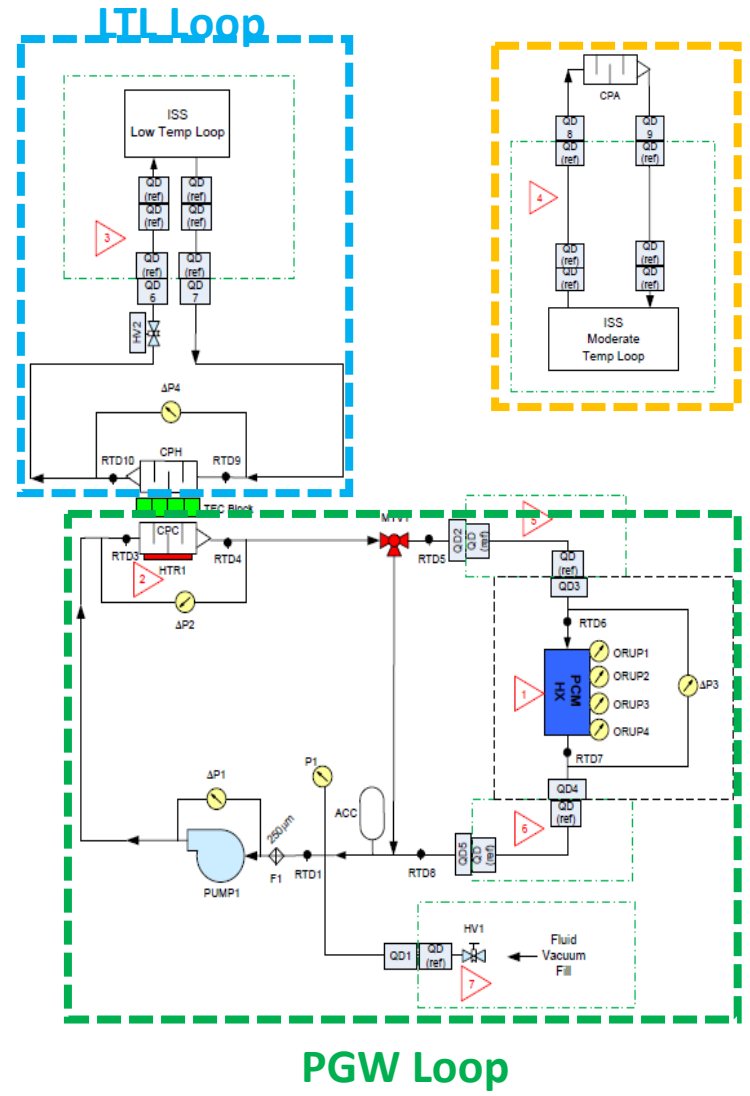
ISS Flight Hardware

- The ISS test rack has a lower and an upper section.
 - The lower section has the a PCHX fluid loop from a previous PCM module test.
 - PCHX loop currently on the ISS, with duplicate loop on ground
 - The dimensions of the upper section, where our experiment would fit is 14" x 13.5" x 7.5" high



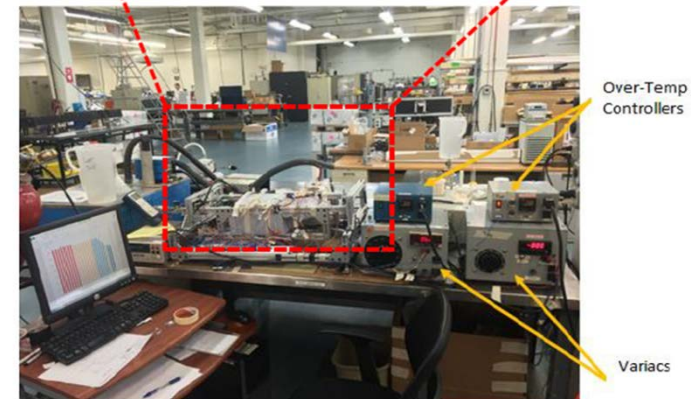
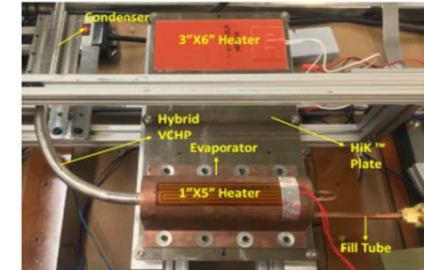
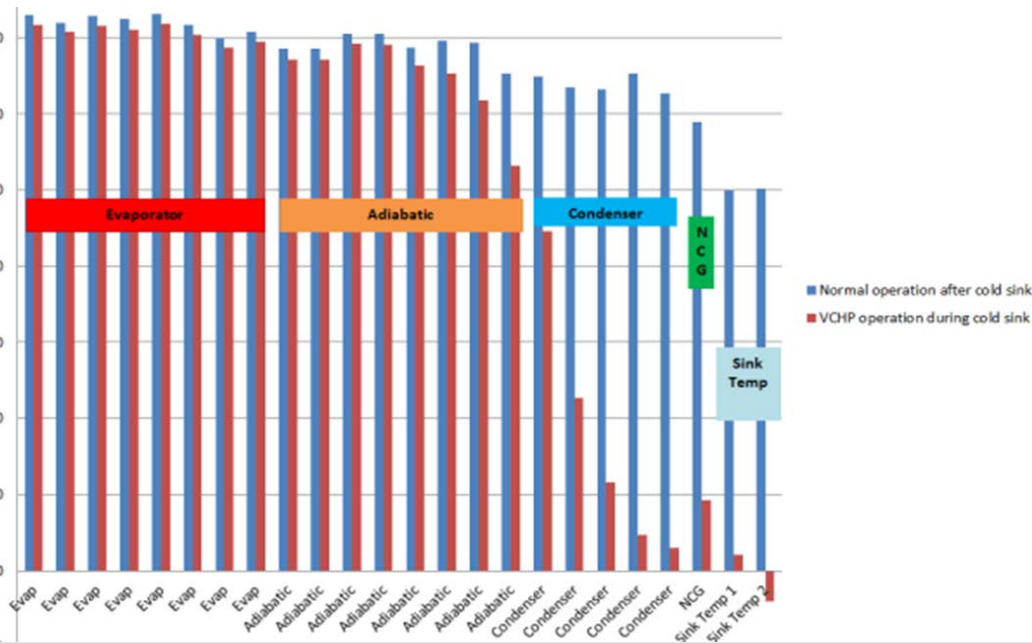
PCHX Flow Loop Schematics

- The fluid system includes a primary PGW Loop with 50/50 Propylene glycol water and an MDP 95 psia (Green Section).
- PCHX flight loop is connected to ISS Low Temp Loop via fluid jumpers
- ISS MTL loop is used to provide cooling to the avionics system (Yellow Section)
- Loop can supply fluid from -10 to 30°C, and remove up to 150 W
- Fluid Temperature set by thermoelectrics



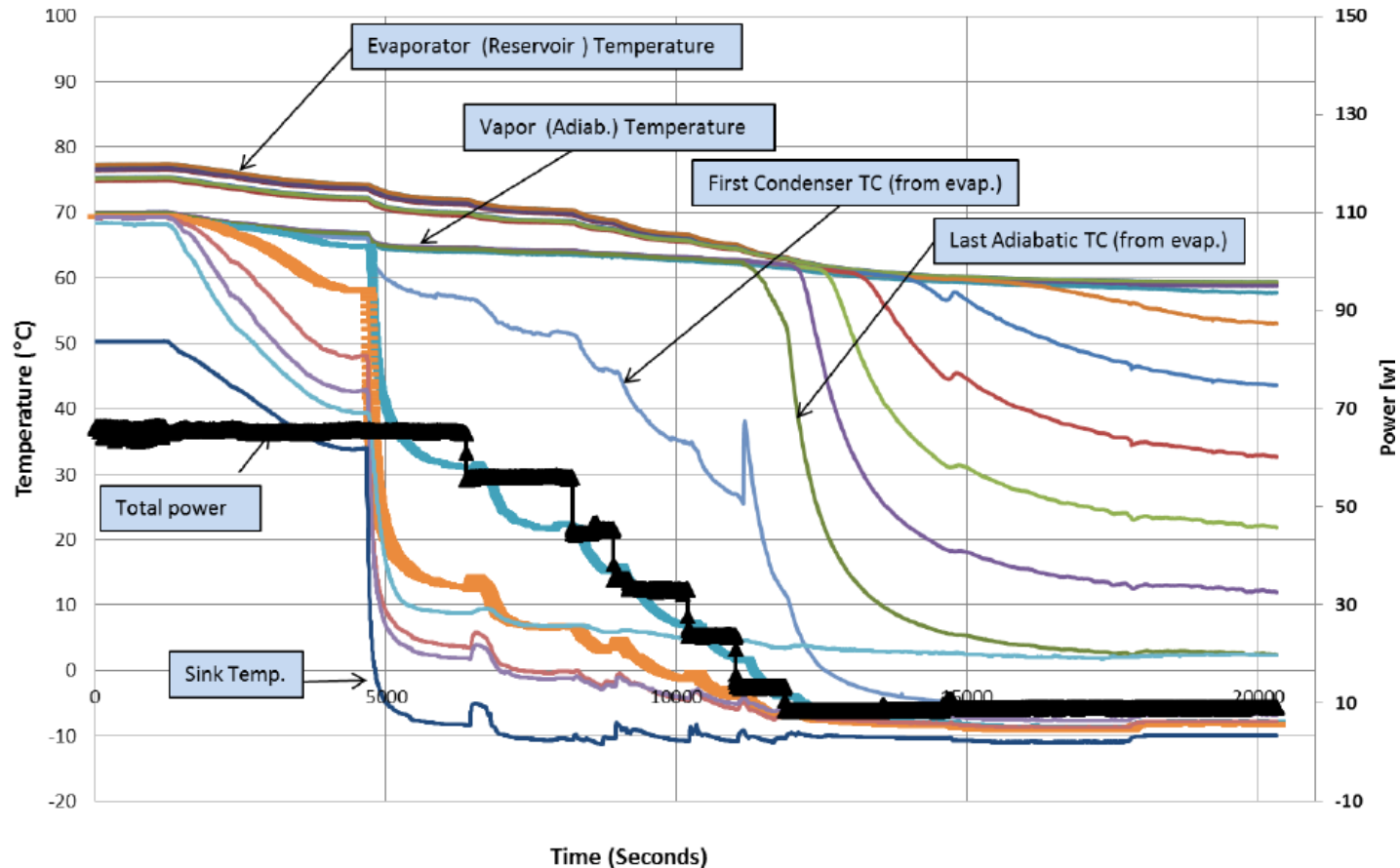
VCHP for ISS Experiment-Payload#1: Ground Testing

- The HiK™ plate in payload 1, which was attached to the copper-monel-water hot reservoir VCHP were tested on ground and on-board ISS.
- The HiK™ plate showed the expected performance in the ISS test and results showed excellent agreement with both predictions and ground testing results.
- The thermal control test on ground at ACT for the hybrid wick VCHP with warm reservoir shows that vapor temperature varies from 69°C to 67°C over widely varying sink temperatures between 50 and -4°C. (See [ICES-2017-272](#): Ababneh et.al for the full details).



(a) blue column or after cold sink (i.e. sink temperature = 50 °C) (b) red column or during cold sink (i.e. sink temperature = -4 °C).

Survival Testing of the VCHP: Ground Testing



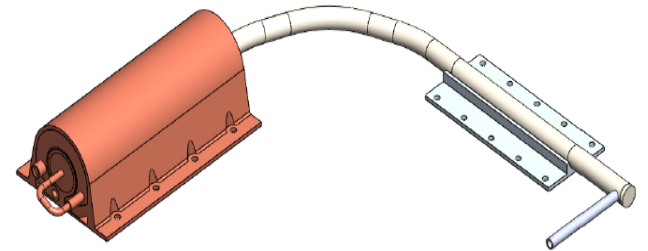
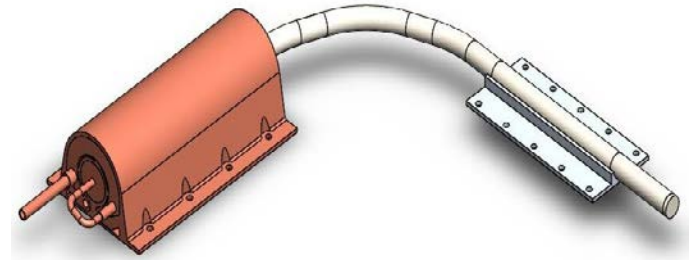
➤ Thermal control survival testing results for the hybrid VCHP / HiK™ plate.

Microgravity Testing of Payload 1 on the ISS

- The VCHP worked on-board ISS, but at higher temperatures than expected.
 - The different behavior in microgravity are primarily due to the lack of natural convection.
- From on orbit testing, valuable insight into integrated reservoir design, concentric return tube, and heat pipe was gained.
- In addition, the first few days of testing demonstrated functionality of the dual wicked system,
 - Providing confidence in the redesigned VCHP for future microgravity operations.
- A new design of the warm reservoir VCHP was developed.

The Modified Warm Reservoir VCHP

- The preliminary thermal testing for the modified VCHP was focused on purging procedure.
 - The new design is considered the lack of natural convection on orbit.
- The fill tube (i.e. that attached to the VCHP's reservoir) accumulates liquid.
 - Therefore, the results are misleading (i.e. purging point of view).
- In order to eliminate this source of instability the fill tube was moved to the of the monel section at the end of the pipe

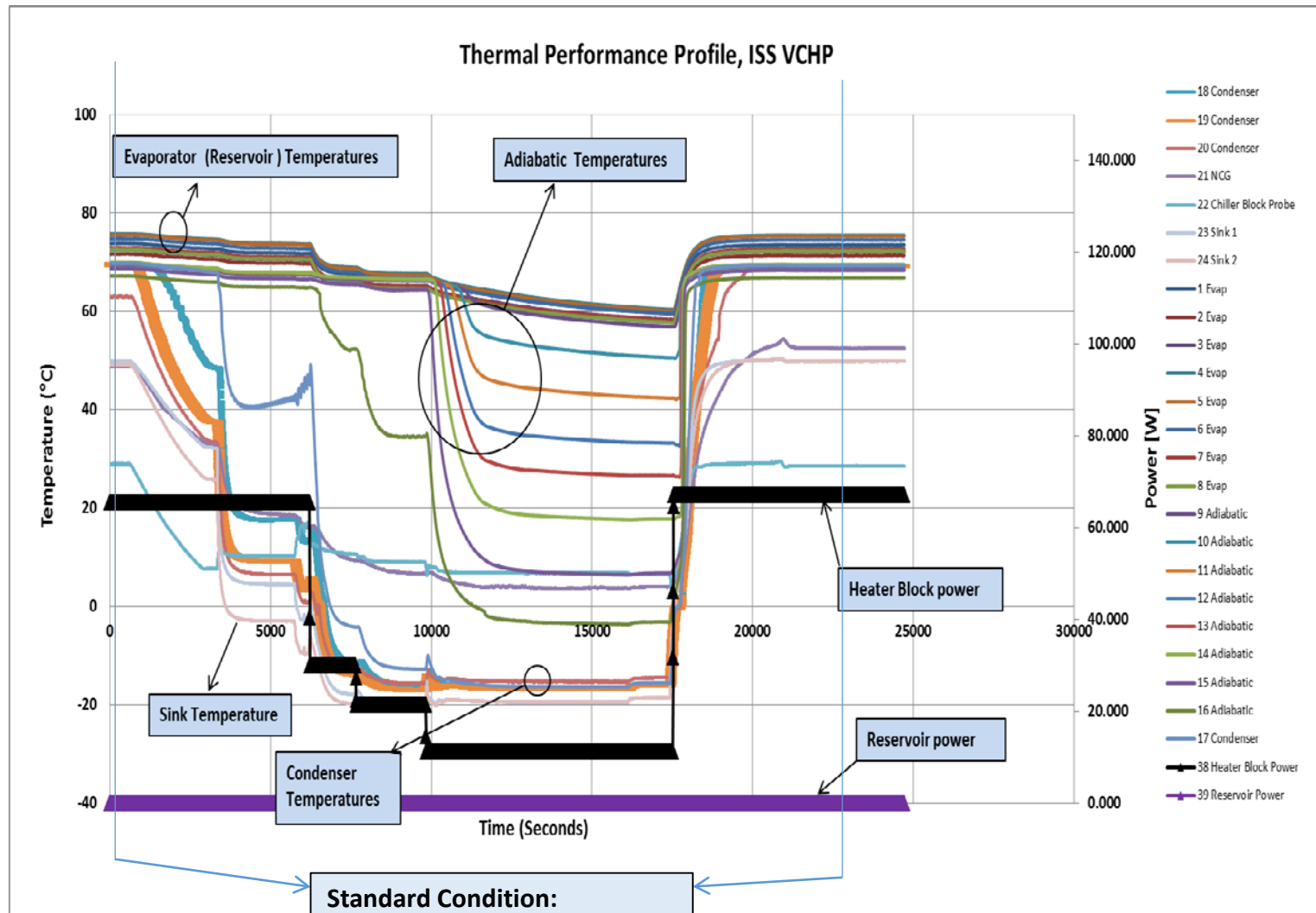


Modified VCHP Testing

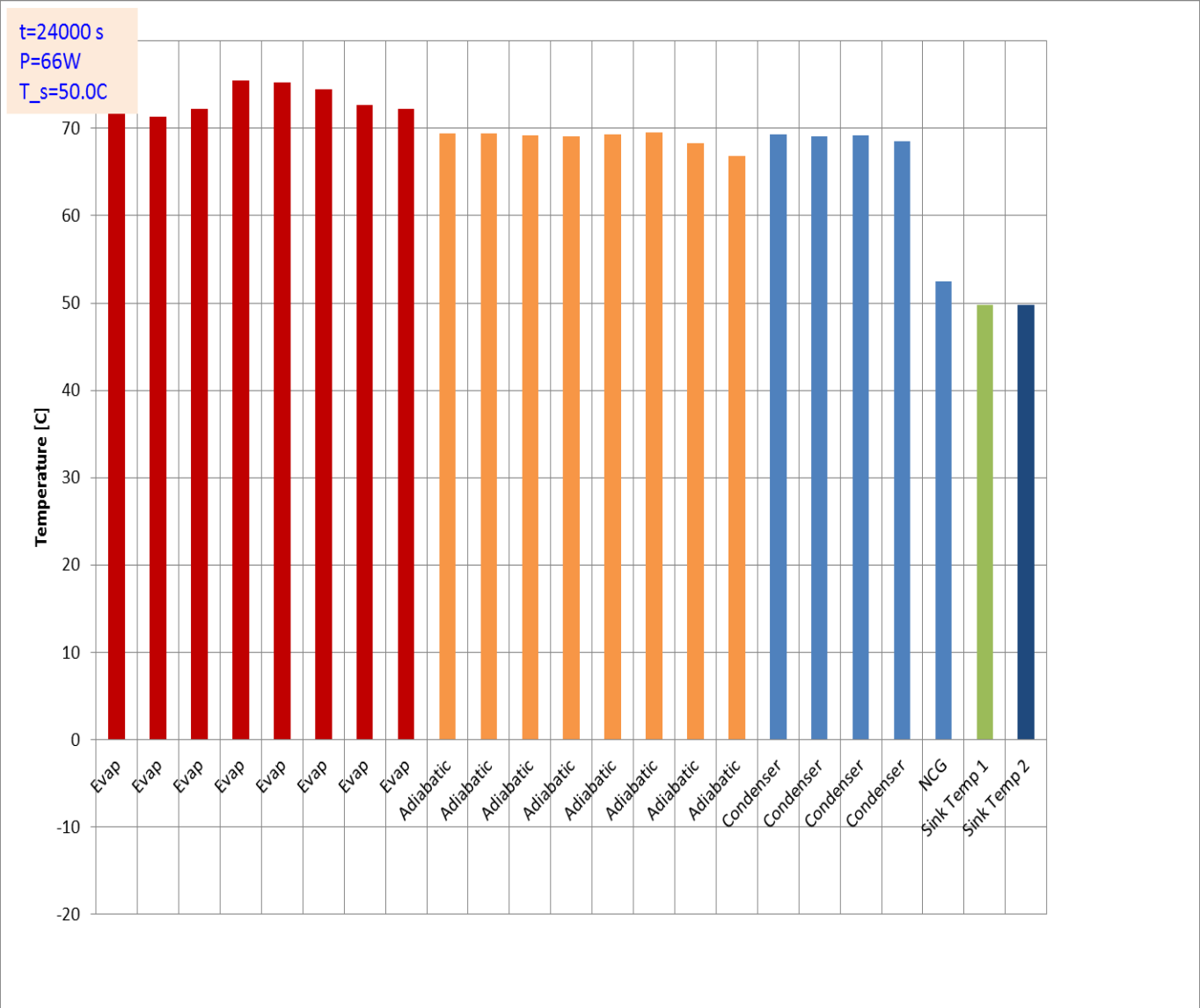


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VCHP Testing Results

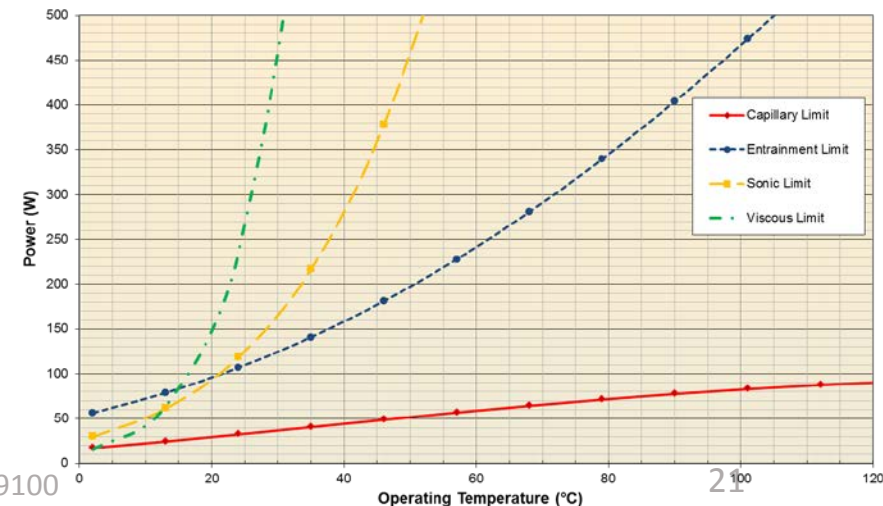
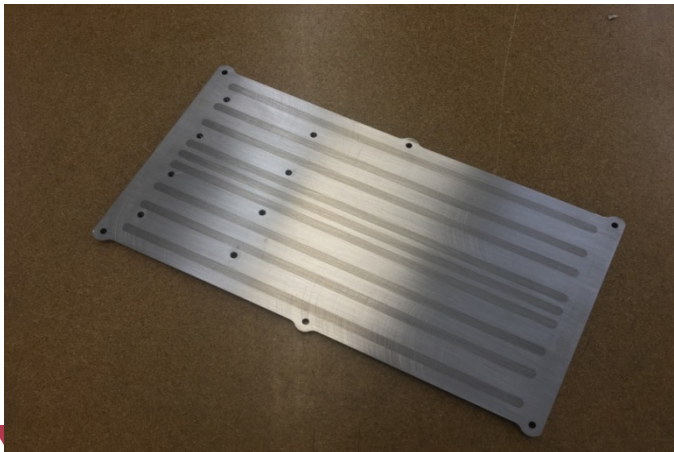
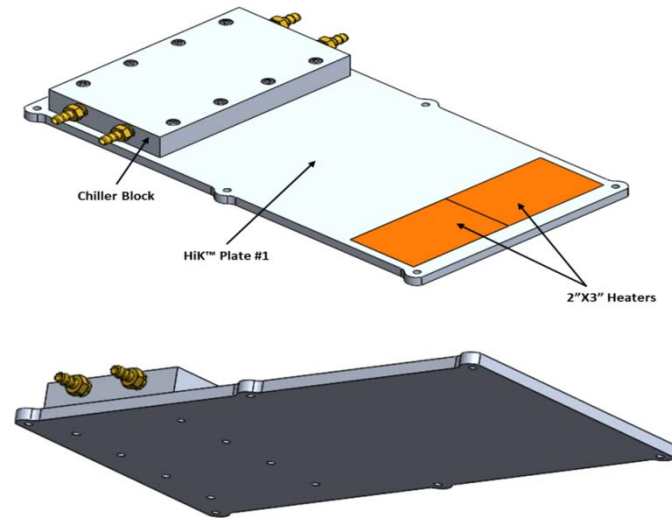


Instantaneous Profile for the VCHP



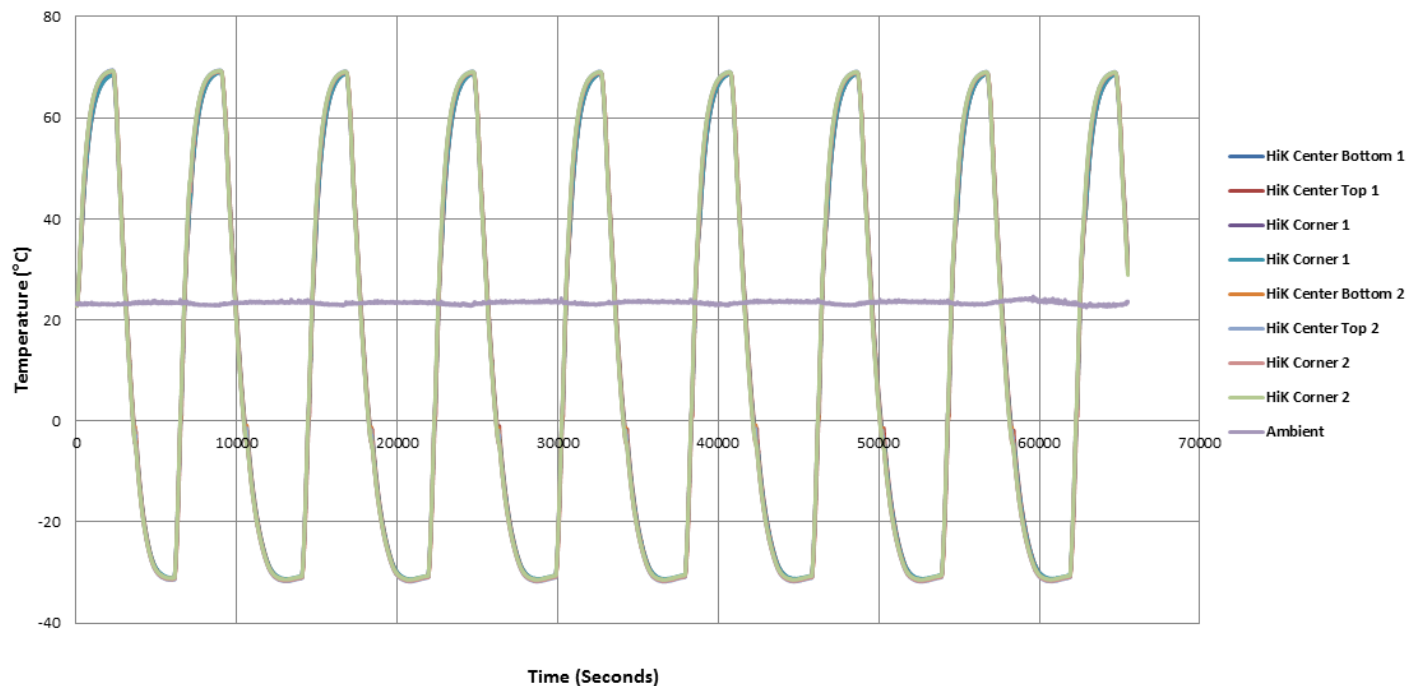
HiK™ Plate for the ISS Experiment in Payload 2: Ground Testing

- Two 53W (2"x3") silicon heaters will be used as a heat source on the top of the HiK™ plate;
- A chiller block was used to impose sink temperatures between -10 to 40°C
- Freeze/thaw testing was performed for the HiK™ plate on the ISS.
- Each HiK™ plate had 9 copper/water heat pipes. Each heat pipe can carry up to 65 W at 70 °C before dryout due to the capillary limit



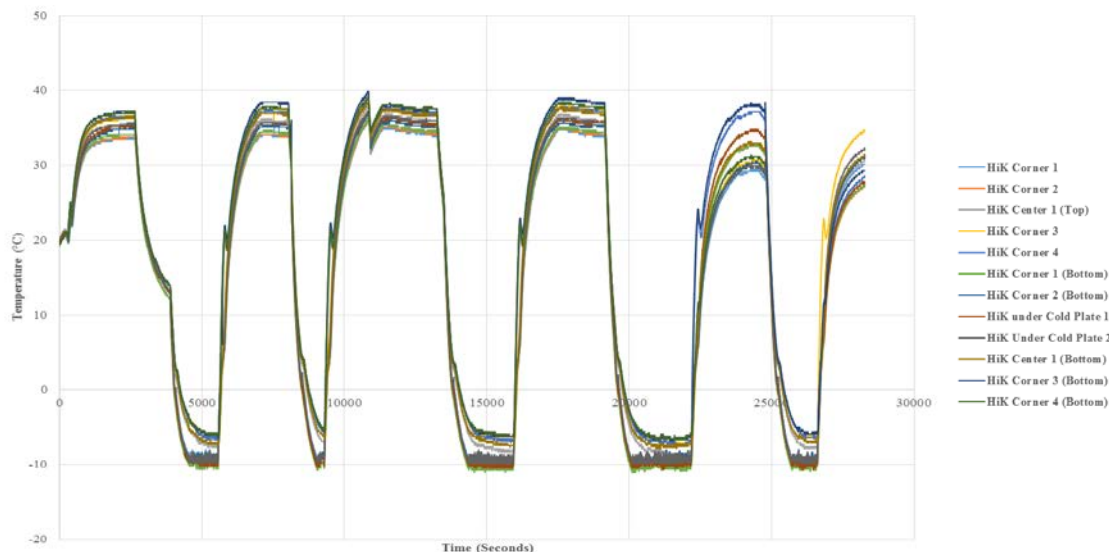
Ground Freeze/Thaw Cycle for HiK™ Plates

- Freeze thaw tests were conducted from temperature ranging from -30 to +70°C for two of the HiK™ plates.
- The plates were subjected to 15 freeze/thaw cycles.
- The embedded copper/water heat pipes can sustain these freeze/thaw cycles without damage.



Microgravity Testing of Payload 2 on the ISS

- Freeze/thaw testing was performed successfully for the HiK™ plate on orbit.
- The freeze/thaw tests were conducted for the HiK™ plate from temperature ranging from -10°C to approximately 40°C.
- Fourteen cycles of freeze-thaw and freeze-startup-thaw cycles were performed on orbit.



The assembled HiK™ plate integrated in Payload 2

Conclusion

- ACT Inc., NASA Marshall Space Flight Center and NASA Johnson Space Center, worked together to test warm reservoir hybrid VCHP and HiK™ plates in the ISS microgravity environment.
- A hybrid wick VCHP and two HiK™ plates were developed and tested on ground and on board ISS.
- The VCHP worked at higher temperatures than expected on ground test due to the evaporator's design that not appropriate for micro-g environment.
- Hence, a new modified warm reservoir hybrid VCHP was developed.
- The thermal control ground test of the modified hybrid wick VCHP with warm reservoir showed that vapor temperature varies from 70°C to 68°C over widely varying sink temperatures between 50 and -7°C.
- The modified warm reservoir hybrid VCHP will be tested in Low-Earth orbit, aboard the ISS tentatively in 2018.

Conclusion

- The flight test verified the operation of the HiK™ plates with the embedded copper/water heat pipes in micro-gravity environment.
- Two HiK™ aluminum base plates were designed, fabricated, and tested successfully in ground and on the ISS.
- In the ISS test for payload 2, the copper-water heat pipes were embedded in a HiK™ plate, and subject to a variety of thermal tests over a temperature range of -10 to 40 °C for a ten-day period.
- Results showed excellent agreement with both predictions and ground testing results.
- The HiK™ plate underwent 15 freeze-thaw cycles between -30 and 70 °C during ground testing, and an additional 14 freeze-thaw cycles during the ISS test.
- This flight test on-board ISS is an important step toward qualifying copper/water heat pipes as a passive thermal management solution in support of future human and robotic space exploration missions by NASA.

Acknowledgements

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- The technicians at ACT were Zack Bitner, Joel Wells and Corey Wagner.
- We would like to acknowledge the help of Ryan Spangler at ACT.



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