



A Mini Loop Heat Pipe Suitable for Mars Rovers

Michael Pauken, Gajanana Birur, and Keith Novak
Jet Propulsion Laboratory
California Institute of Technology, Pasadena, California

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OUTLINE



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- **LHP Design Requirements for Landed Mars Missions**
 - **Description of Prototype Mini Loop Heat Pipe**
 - **Development Test Program**
 - **Discussion of Test Results**
 - **Conclusions**



LHP Design Requirements for Landed Mars Missions



- The mini-LHP must operate in the extreme Martian environment.
- Condenser must survive a temperature range of -120° to $+65^{\circ}\text{C}$ for at least 100 freeze/thaw cycles
- Evaporator must operate over a temperature range of -15° to $+70^{\circ}\text{C}$
- Capable of transporting 20 to 100 watts of heat
- Reliably start with evaporator attached to 3 kg of aluminum mass
- Reliably stop with 1 watt applied to the compensation chamber
- Thermal conductance from evaporator to condenser must be greater than 10 $\text{watts}/^{\circ}\text{C}$
- Must withstand landing loads up to 45-g.



Description of Prototype Mini Loop Heat Pipe



- Aluminum evaporator houses a porous sintered nickel wick
- Evaporator has a fin for mounting start-up heaters to provide locally high heat flux
- The radiator is an aluminum panel bonded to a stainless steel condenser line
- Ammonia is used as the working fluid
- The heavy wall stainless steel transport lines have coiled loops to give flexibility between the evaporator and the radiator

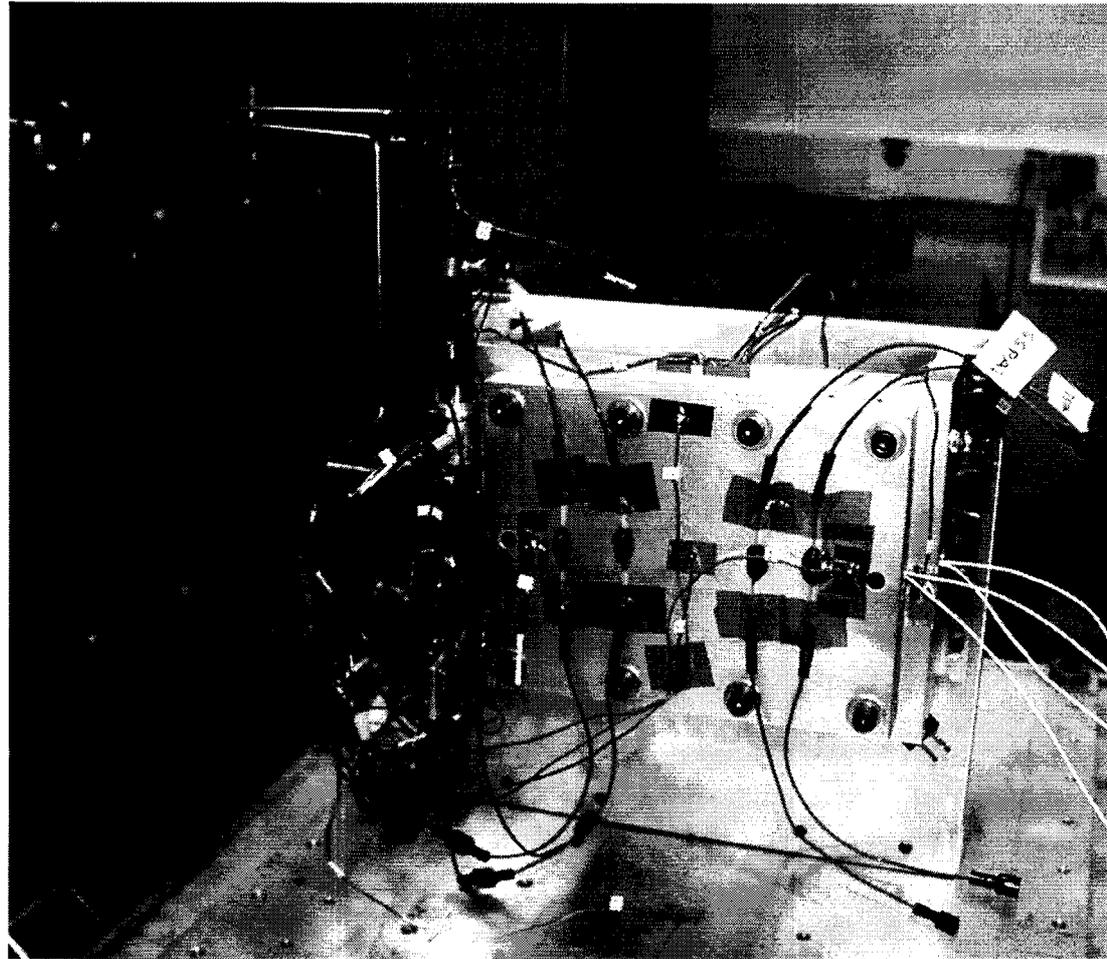


Description of Prototype Mini Loop Heat Pipe

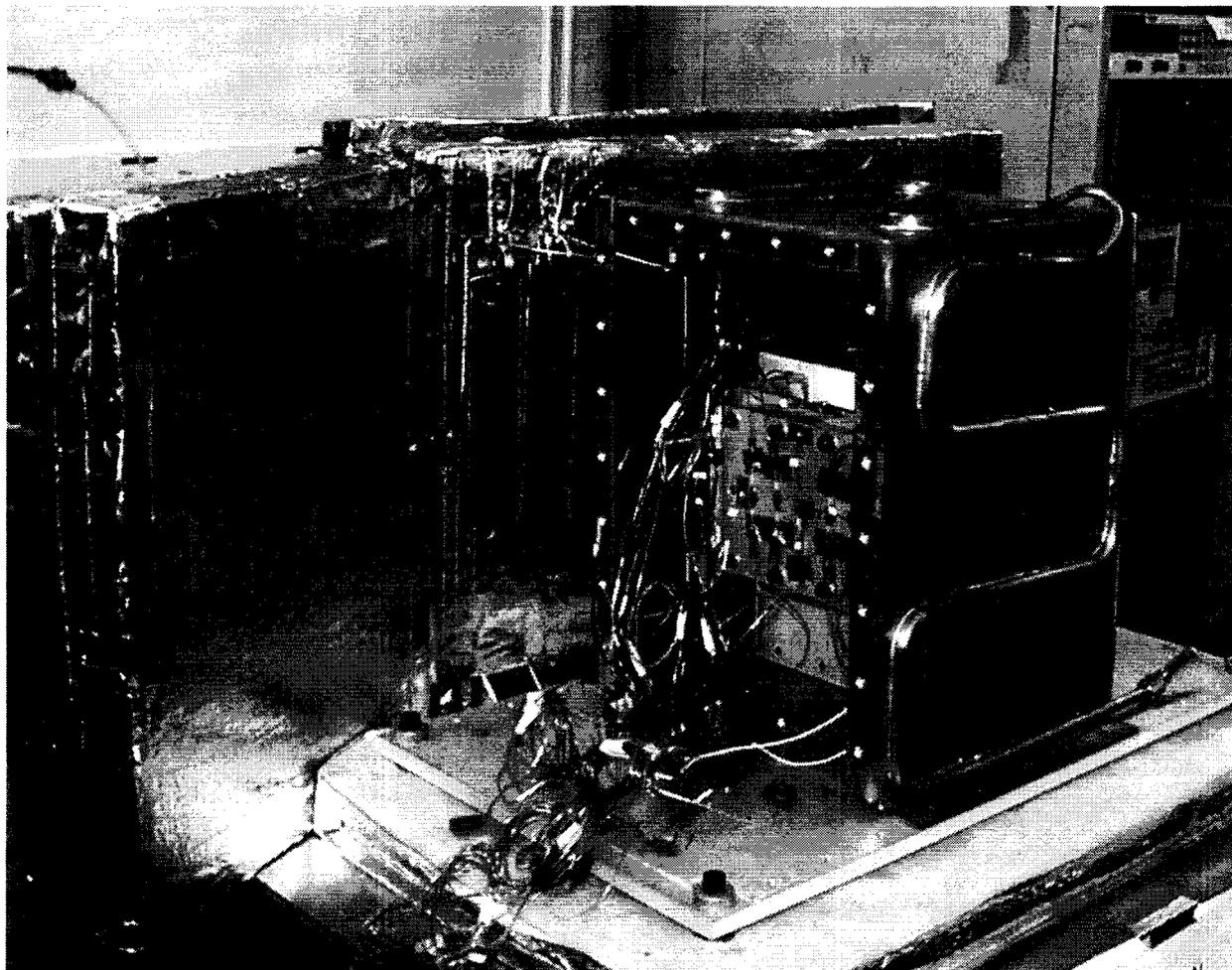


Photograph of the mini-LHP developed for Mars Rovers

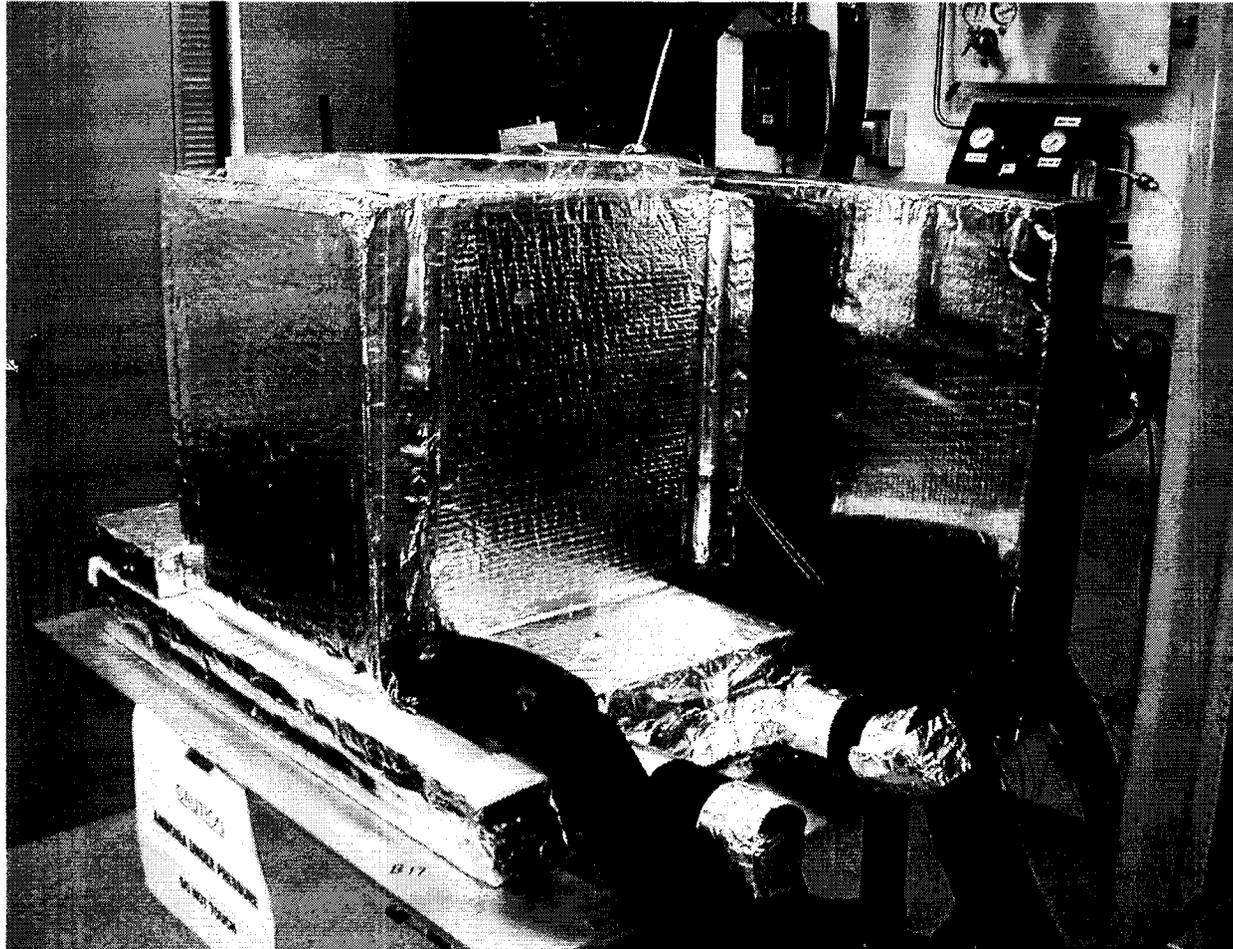
- The mini Loop Heat Pipe was subjected to the following tests:
- Measure thermal conductance from evaporator to radiator
 - Construct a thermal performance map for a range of sink temperatures and evaporator loads
- Start-up at 20 watts with evaporator attached to 3-kg aluminum
 - Test effectiveness of 5 watt start-up heater on evaporator fin
- Shut-off with 1 watt applied to the compensation chamber
- Freeze/thaw the ammonia in the radiator 100 times



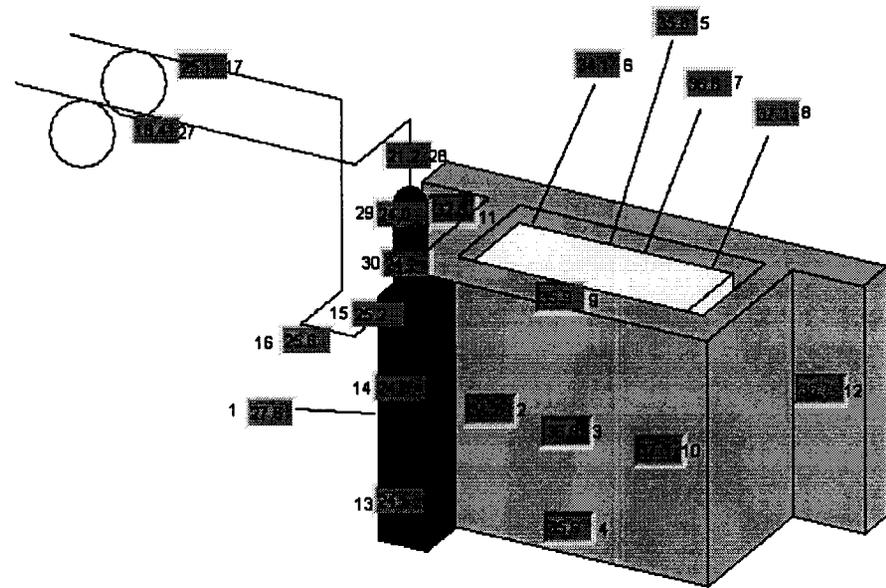
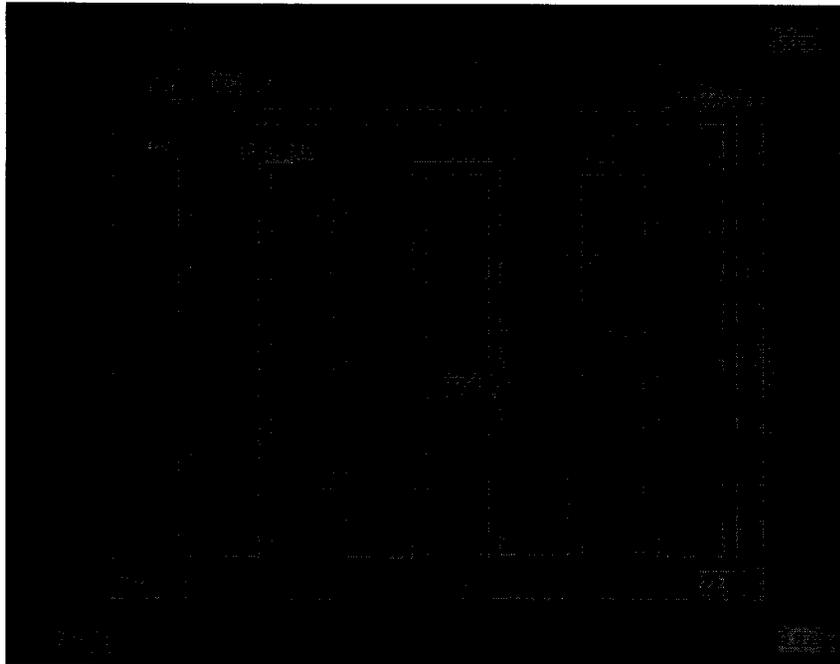
LHP Evaporator mounted to an aluminum mass



Mini-LHP mounted within a temperature controlled enclosure

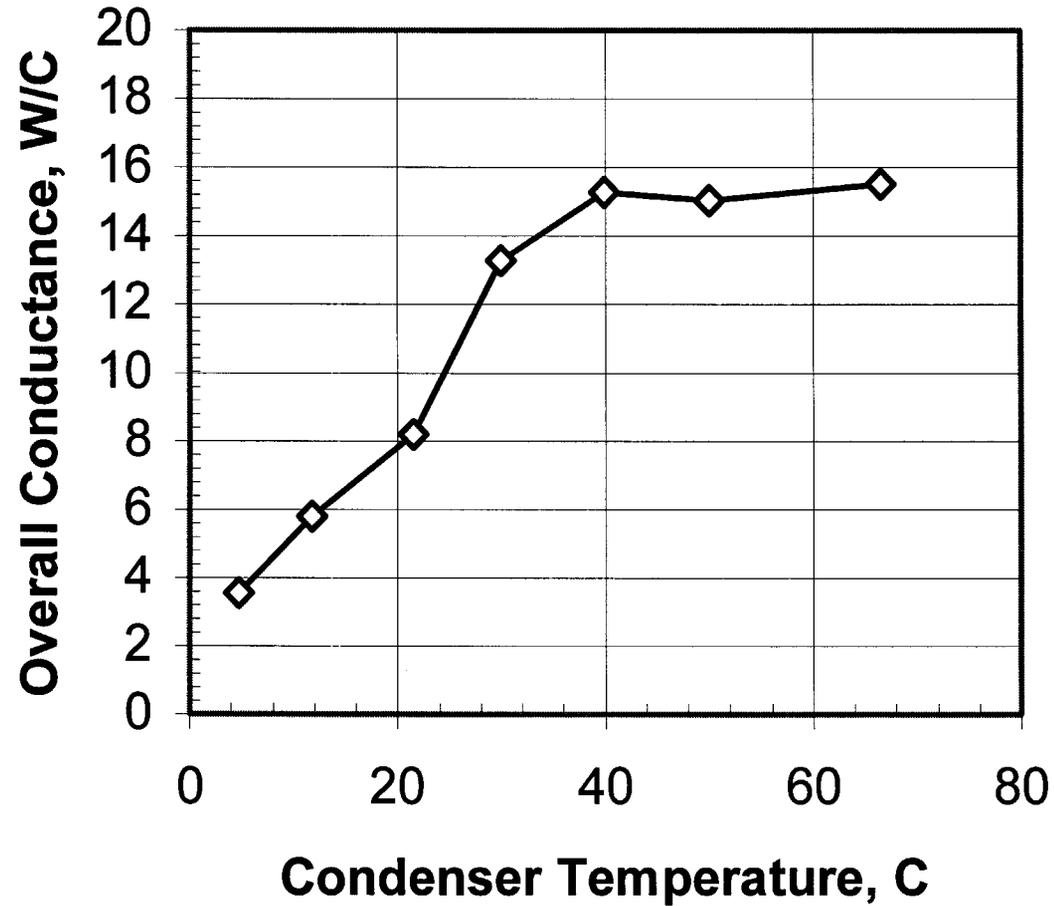


LHP evaporator and radiator in separate enclosures



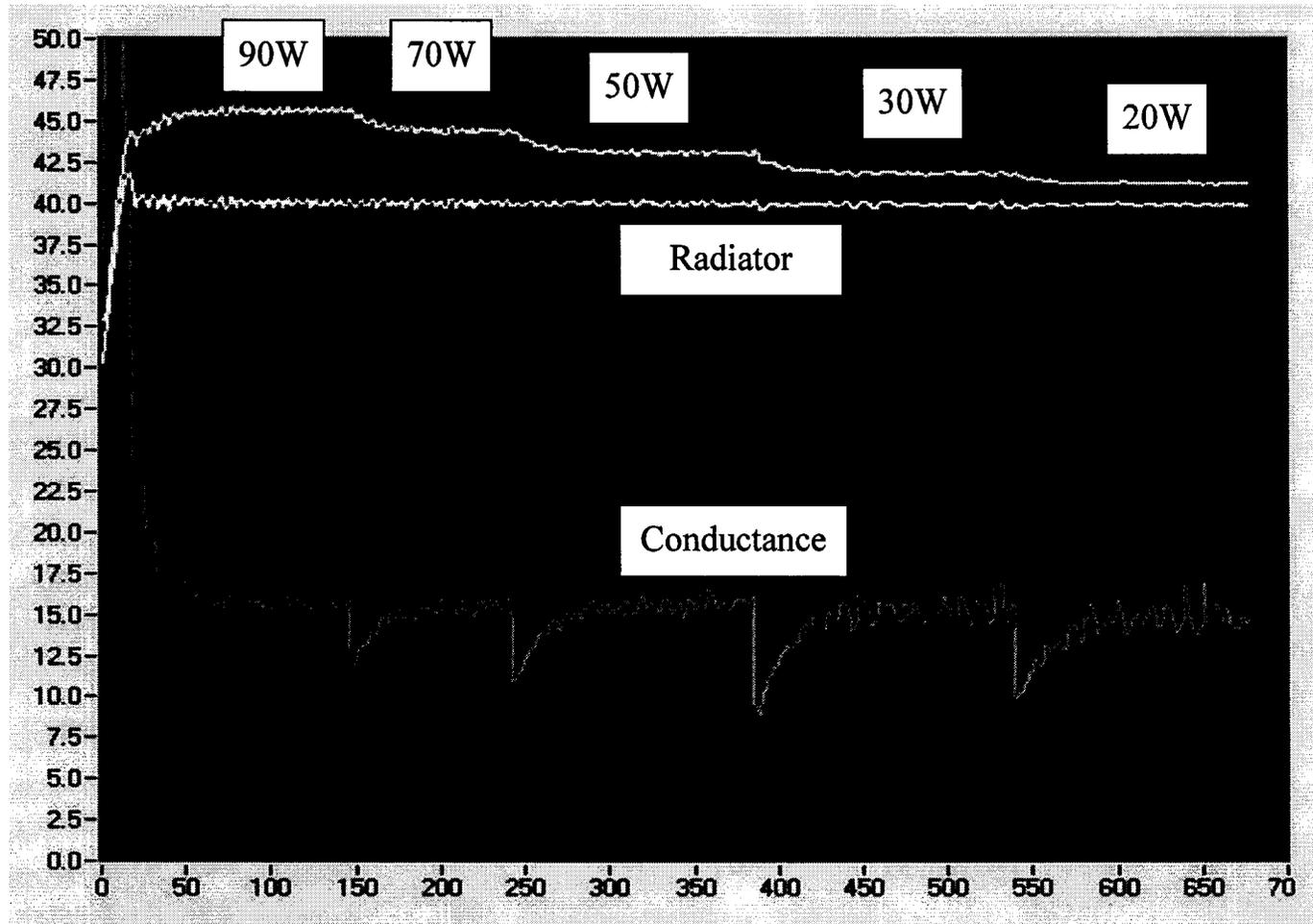
Thermocouple locations for thermal test program

- Thermal conductance measurement of the LHP for a typical electronic component heat load:
 - Point design heat load was 36 watts
 - Upper allowable flight temperature (AFT) of component was 50°C
 - Evaporator temperature at component (AFT) is about 45°C
 - Sink temperature for radiator could range from 0 to 30°C

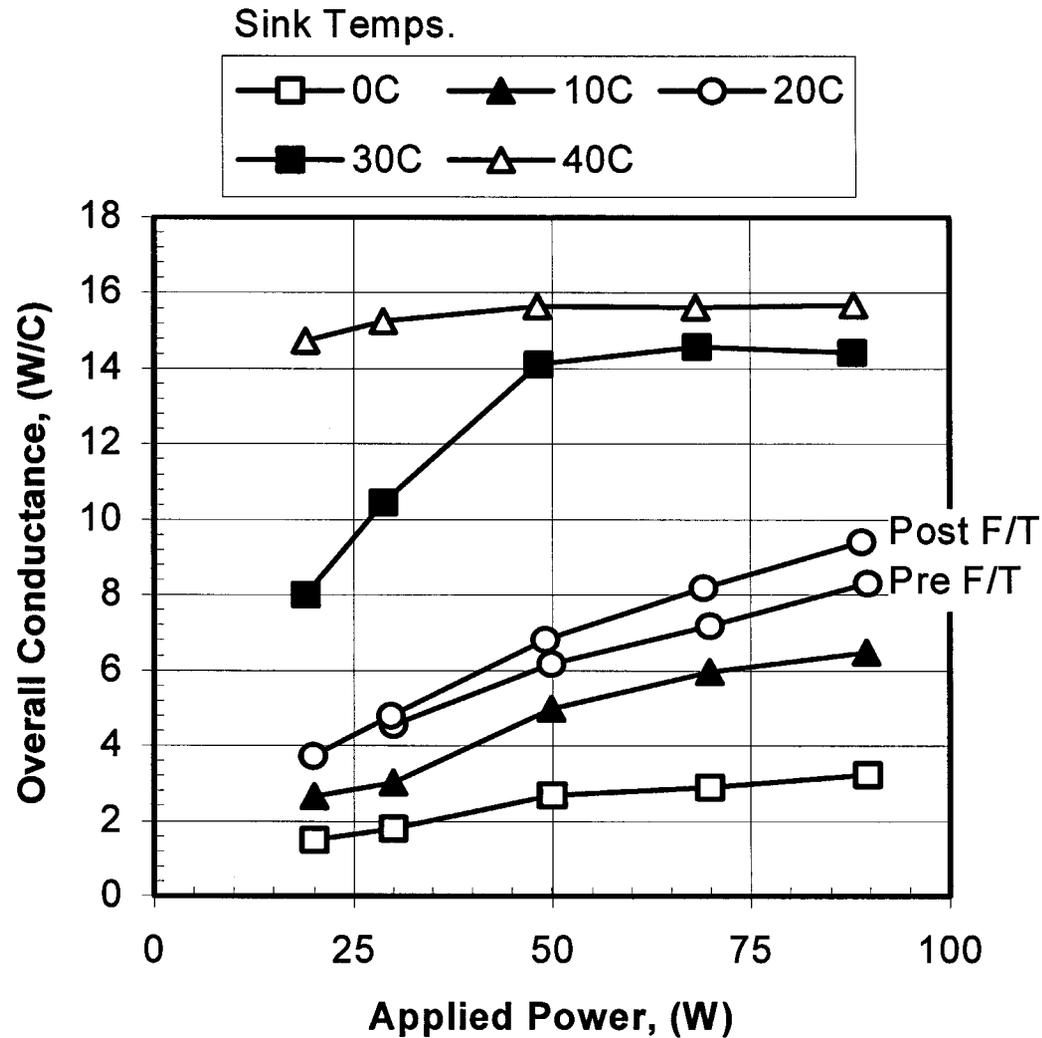


Effect of condenser temperature on source to sink conductance

- Thermal performance mapping of the LHP for a range of electronic component heat loads:
 - Heat load range was from 20 to 90 watts
 - Power steps were: 50, 70, 90, 70, 50, 30, 20, 30, 50 watts
 - Checked for hysteresis, checked conductance at 50 watts three times
 - Identified fixed and variable conductance regions of the LHP
 - Sink temperature for radiator range was from 0 to 40°C

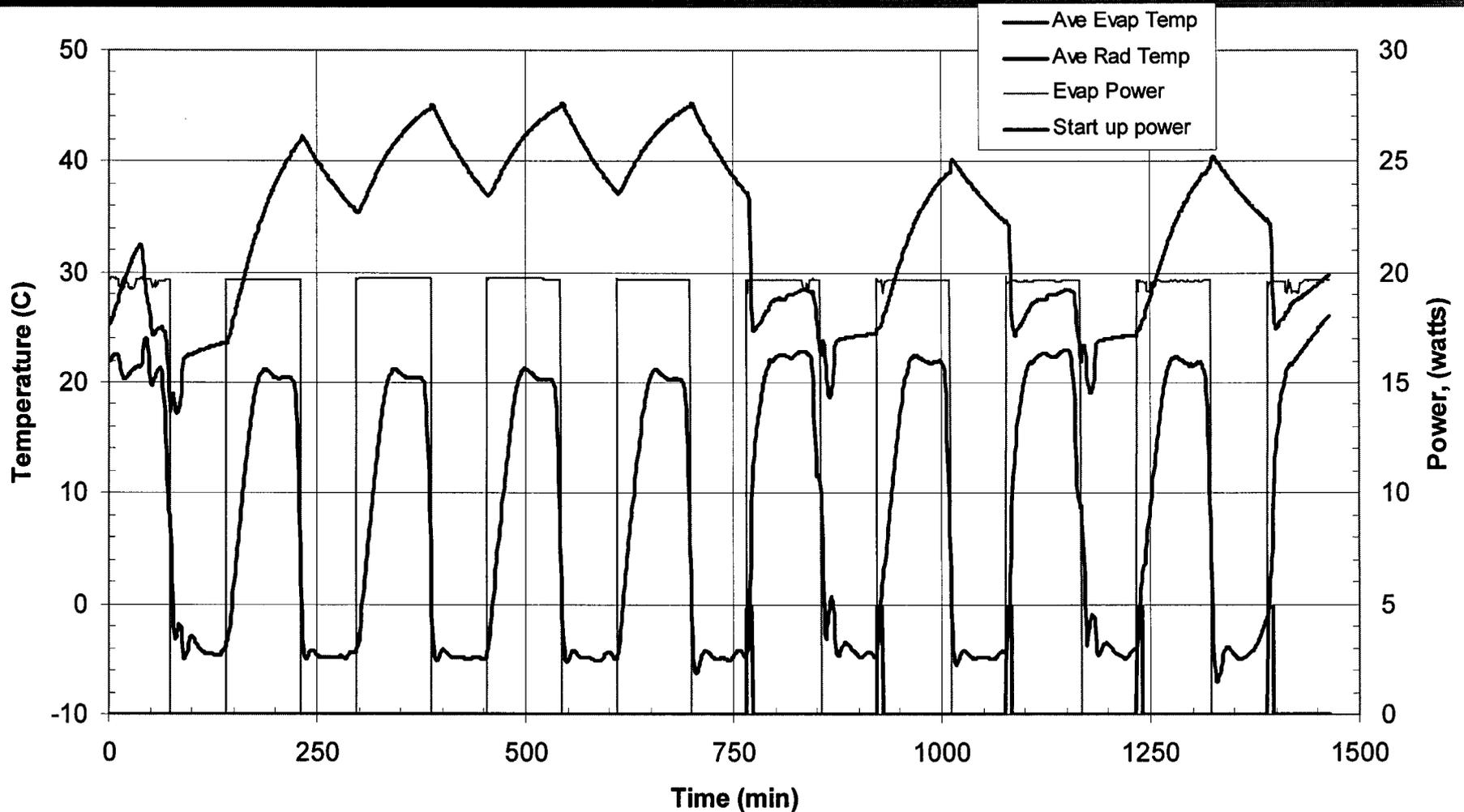


Typical performance test with 20 to 90 watt load and 40°C radiator



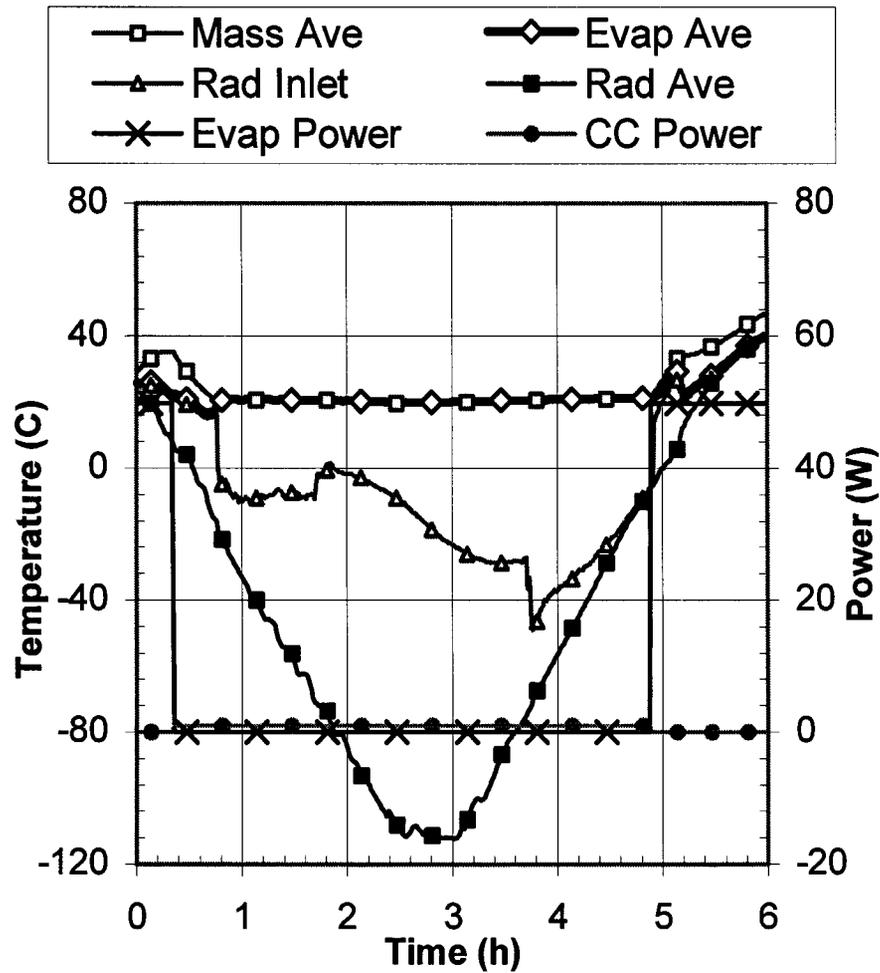
Thermal conductance for a range of heat loads and sink temperatures

- LHP start-up testing compared performance with and without the start-up heater
 - A 5 watt heater was bonded to a fin located on the evaporator as far from the compensation chamber as possible
 - The evaporator heat load was 20 watts
 - The evaporator was attached to a 3 kg aluminum mass
 - The radiator sink temperature was cycled between -5 and $+20^{\circ}\text{C}$ to mimic a rising environment temperature during Mars surface operations
 - Use of the start-up heater showed performance improvement over start-ups without it



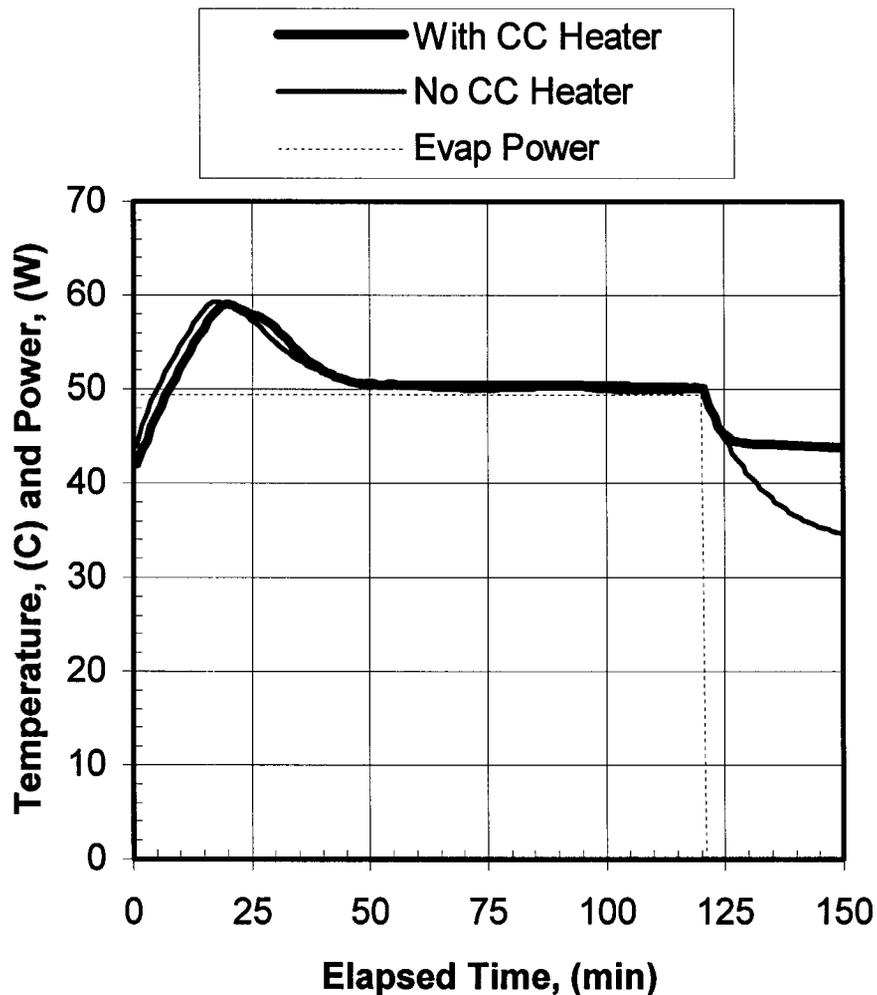
LHP start comparison with and without start-up heater

- Freeze/thaw cycling of the ammonia filled radiator
 - The radiator sink temperature was cycled between -120 and +40°C over 100 times
 - (Designed for a 90 sol mission)
 - A 40 watt heat load was applied to the evaporator when the radiator temperature was above 0°C
 - The LHP started every time
 - No significant performance degradation was observed after the freeze/thaw cycling test



Component temperatures during a typical freeze/thaw test

- LHP shut-off test using a compensation chamber heater
 - Used 1 watt heater to stop LHP heat transport when electronic component was powered off
 - Saves thermal energy by keeping component warm rather than continued heat removal after powering off electronic component
 - Saved 27kJ of energy on a 3 kg aluminum mass



Thermal mass temperature comparison with and without shut-off heater



Conclusions



- The mini Loop Heat Pipe met the following requirements:
 - Transport 20 to 100 watts from the evaporator to the radiator
 - Overall conductance was 15 W/C with fully active radiator
 - No performance degradation after freezing/thawing ammonia in radiator 100 times
 - Quickly shut off with 1 watt applied to compensation chamber
 - Reliably started with 20 watts on 3 kg aluminum mass
 - Flight qualified to survive more than 45-g landing loads