A Thermal Performance Evaluation of a Small Loop Heat Pipe for Space Applications

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OUTLINE

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LHP Design Requirements

- The LHP must operate in the extreme Martian environment.
- Condenser must survive a temperature range of –120° to +65°C for at least 100 freeze/thaw cycles
- Evaporator must operate over a temperature range of -15° to +70°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 watts/°C
- Must withstand landing loads up to 45-g.

Description of Prototype 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

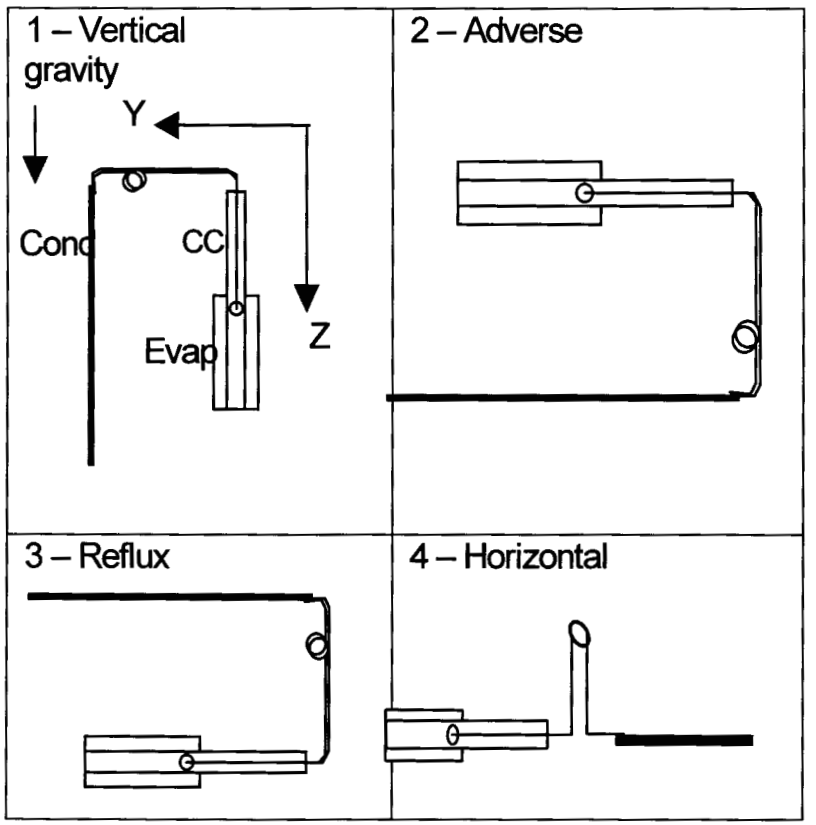
Description of Prototype Loop Heat Pipe

Photograph of the small LHP developed for space applications

Development Test Program

- The 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

Development Test Program



Loop Heat Pipe Testing Orientations

Development Test Program

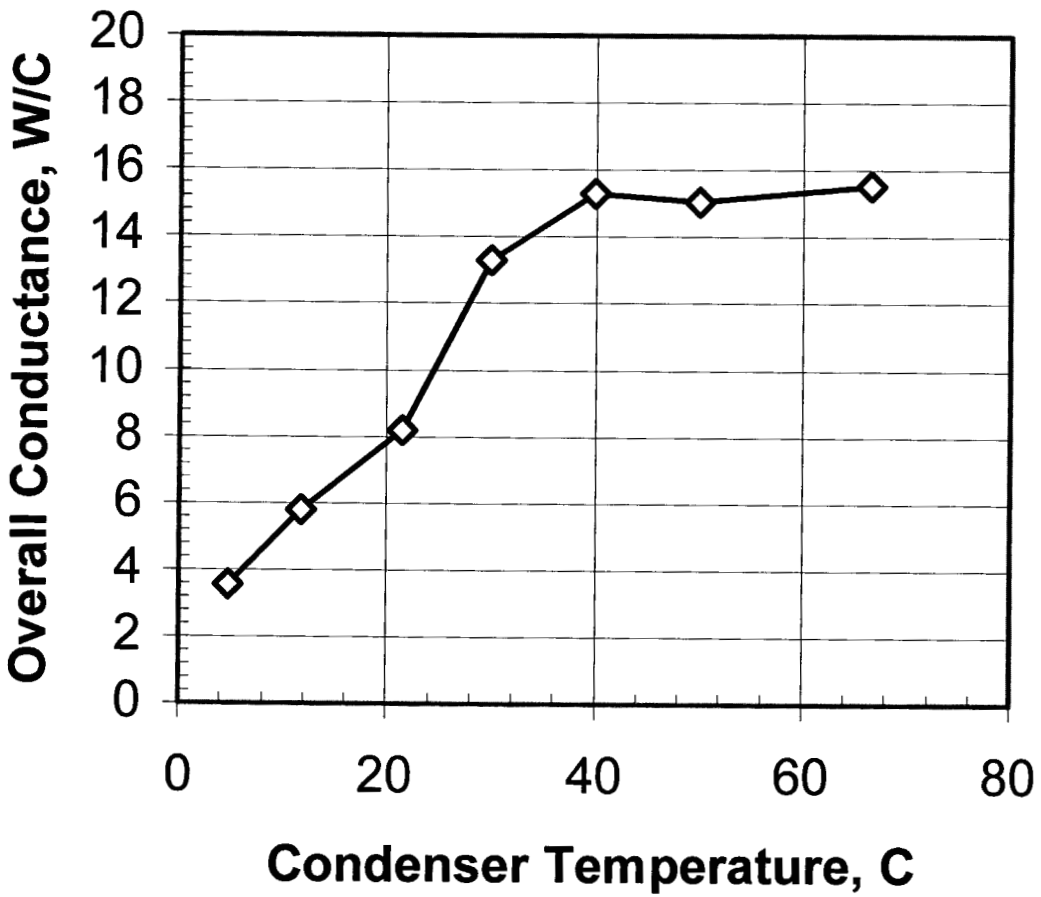
Orientations	Thermal Tests	Sink Temp
1 - Vertical 2 - Adverse 3 - Reflux	Startup	Hot Sink (0°C)
		Cold Sink (-5°C)
	Shutoff	Hot Sink (30°C)
		Cold Sink (-20°C)
	Steady State	Hot Sink (37°C)
		Cold Sink (-50°C)
	Transient	Hot Sink (37 °C)
		Cold Sink (-50°C)
		Sink Transient (37°C → -50°C)
4 - Horizontal	Startup	Hot Sink (0°C)
		Cold Sink (-50°C)
	Shutoff	Hot Sink (30°C)
		Cold Sink (-20°C)

Thermal Performance Test Type, Orientations, and Sink Temperatures

Discussion of Test Results

- 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

Discussion of Test Results

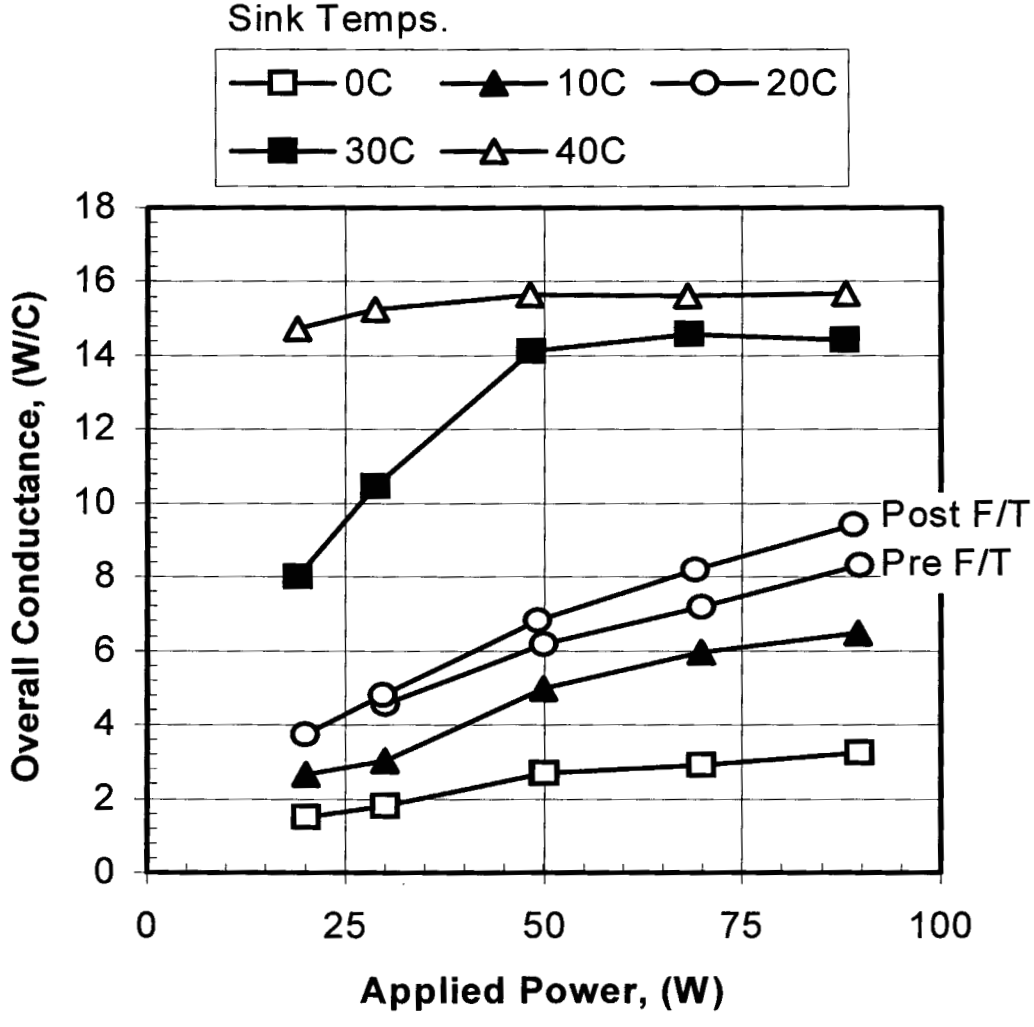


Effect of condenser temperature on source to sink conductance

Discussion of Test Results

- 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

Discussion of Test Results

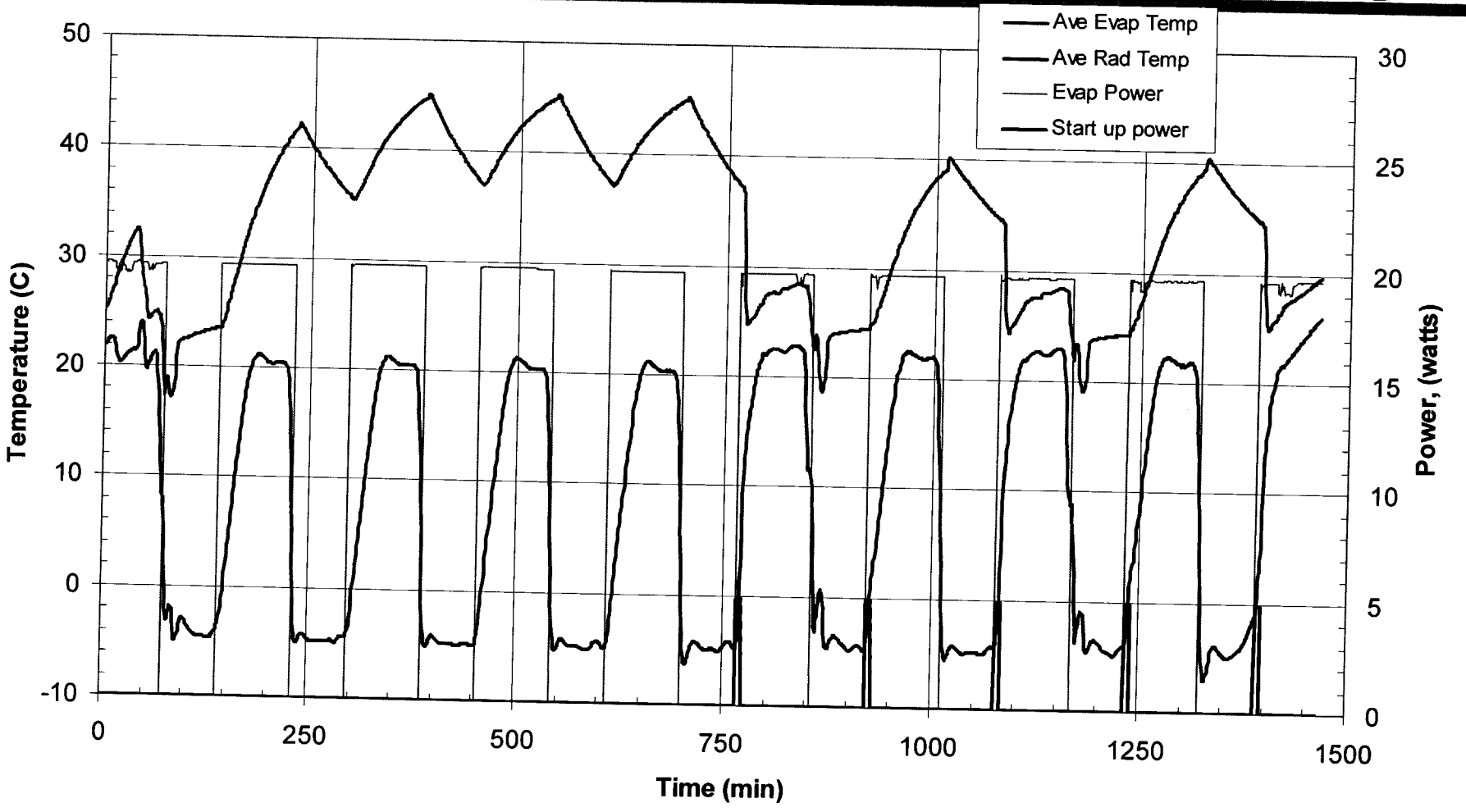


Thermal conductance for a range of heat loads and sink temperatures

Discussion of Test Results

- 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°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

Discussion of Test Results

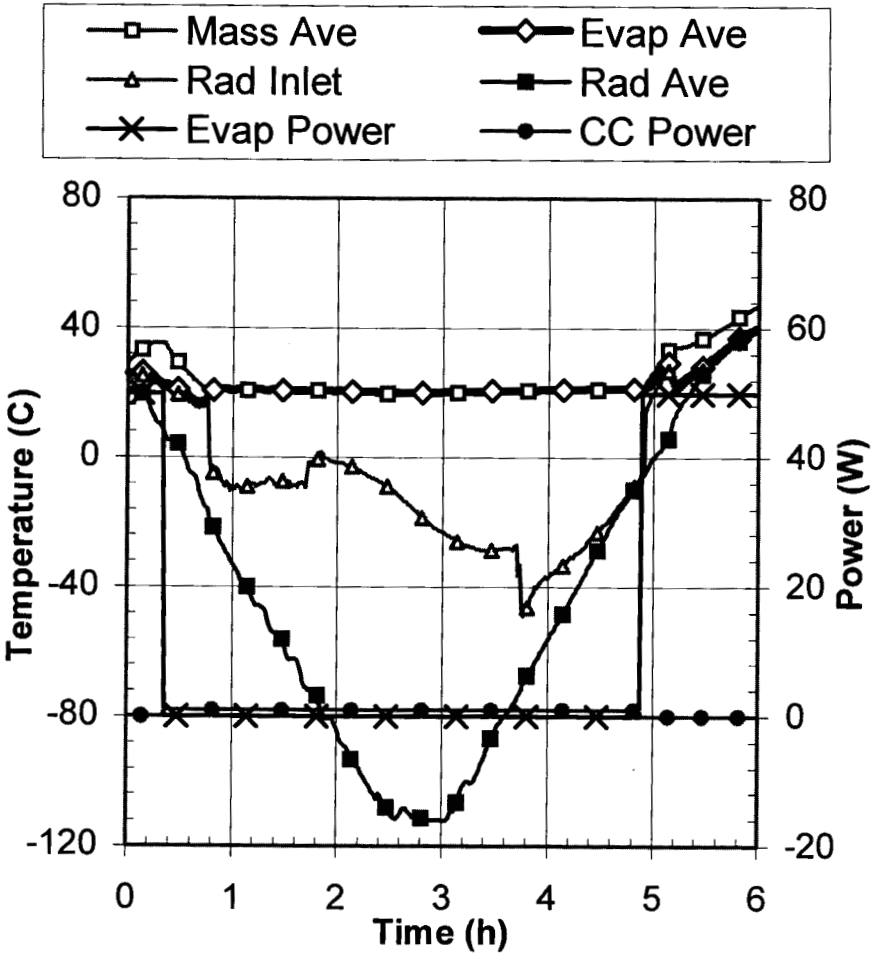


LHP start comparison with and without start-up heater

Discussion of Test Results

- 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

Discussion of Test Results

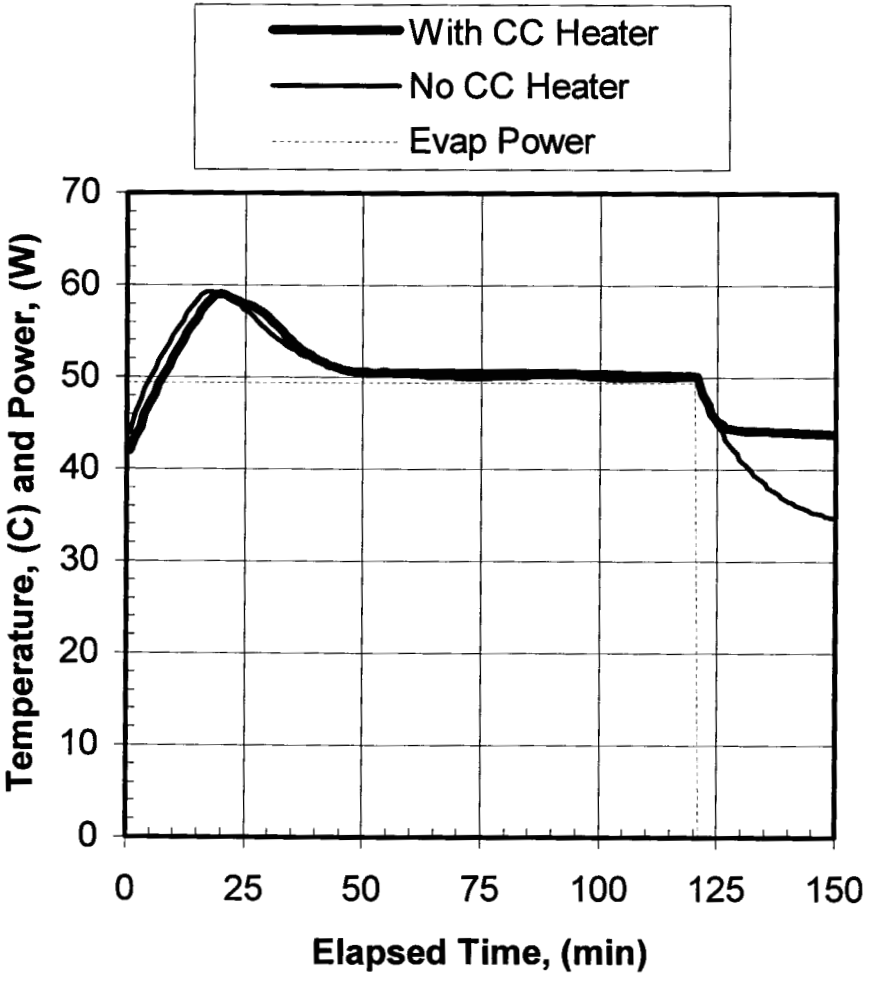


Component temperatures during a typical freeze/thaw test

Discussion of Test Results

- 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

Discussion of Test Results



Thermal mass temperature comparison with and without shut-off heater

Conclusions

- The 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