Thermal Control of Mars Rovers and Landers Using Mini Loop Heat Pipes

Gaj Birur, Mike Pauken, and Keith Novak
Jet Propulsion Laboratory
California Institute of Technology, Pasadena, California, USA

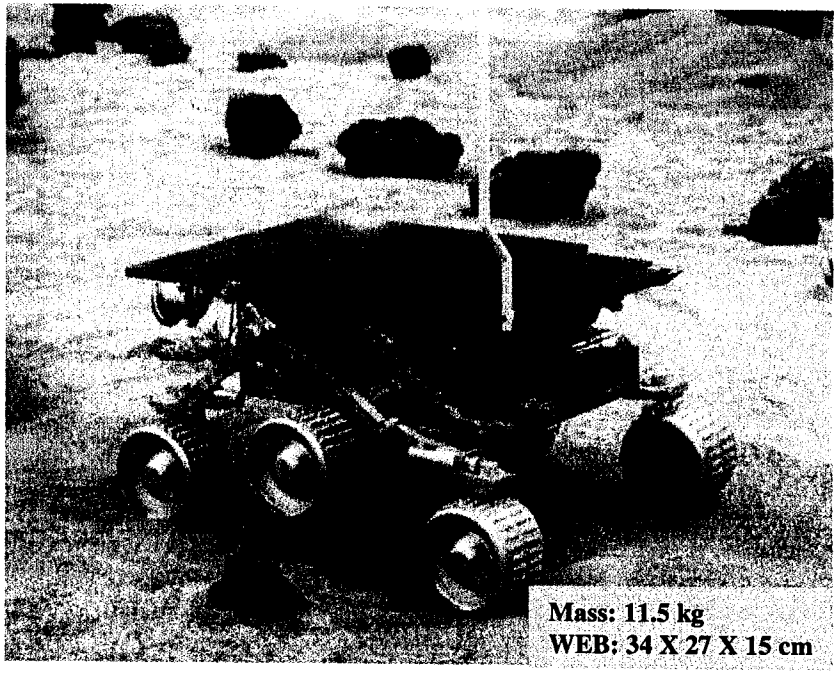
May 19-24, 2002

Presented at
12th International Heat Pipe Conference
Moscow, Russia

Mars Surface Missions

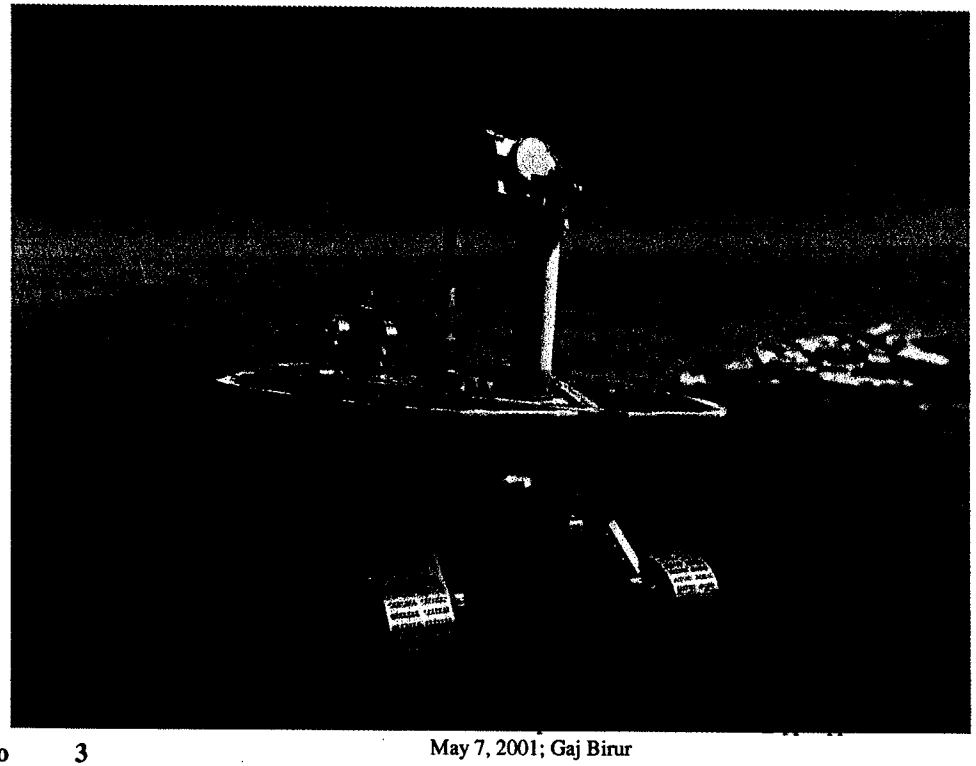
- In the early 90's Mars was designated by the international space agencies for exploration during the next 15 years
- Scientific interest is in the existence of life on Mars along with better understanding of our sister planet
- Past surface missions include Viking (1975), Mars Pathfinder (1996)
- Several upcoming Mars missions
  - MER (03), Mars Beagle (ESA), Mars Scout missions, Mars Smart Lander (09), Mars Sample Return (11)
  - Landers, rovers, in-situ production experiments, and robotic support for human colonization

Mars Rovers



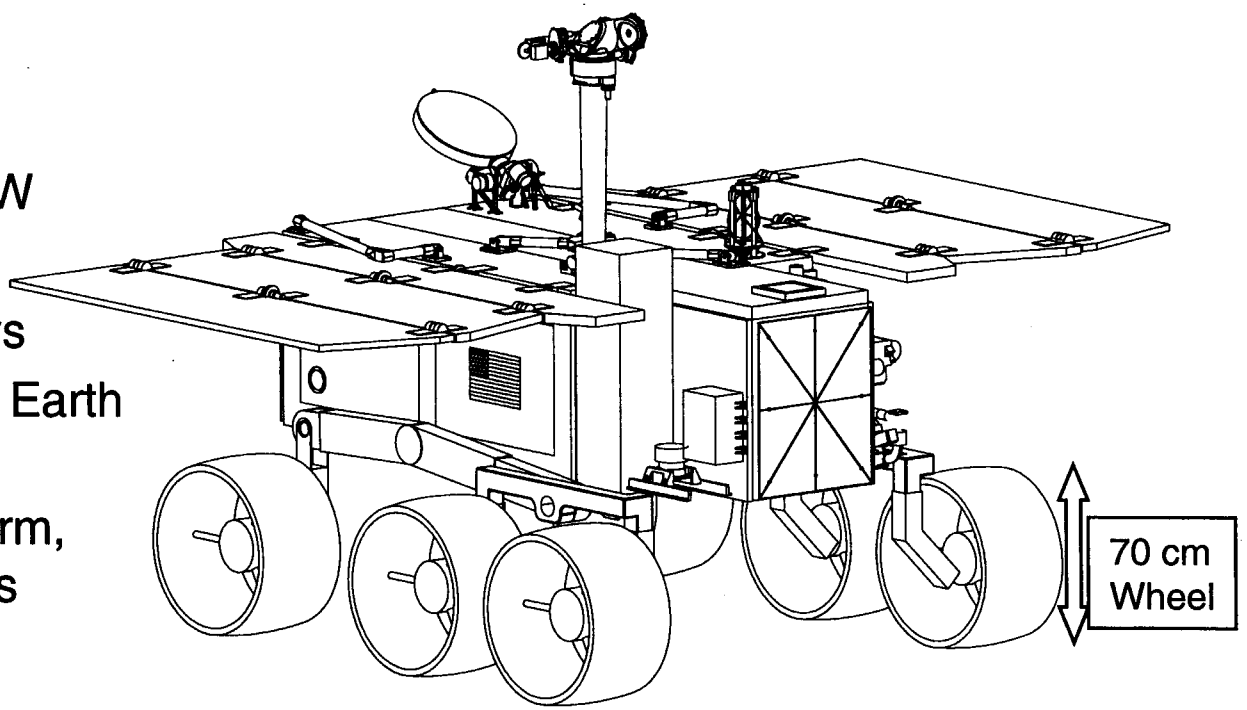
Mars Pathfinder Rover (1996)
Mass: 11.5 kg
Power: 15 W
Life: 30 days

Mars Exploration Rover (2003)
Mass: 150 kg
Power: 150 W
Life: 90 days



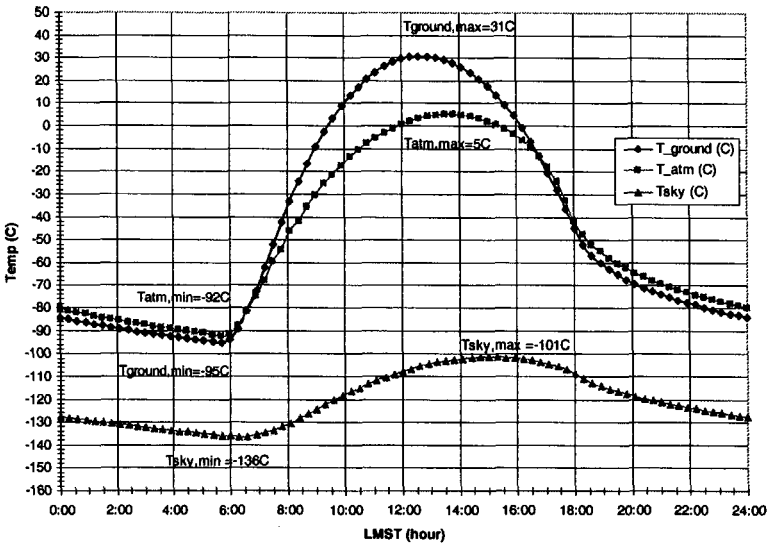
Thermal Control for Future Mars Rovers

- Mass = 200- 750 kg
- Solar Array Area = 7.0 m^2
- Wheel diameter = 70 cm
- Max Power = 100 to 175 W
- Secondary Battery
- Design Life = 90 -180 days
- Telecom links to orbiter & Earth
- Payload: cameras, spectrometers, instrum. arm, drill, sample cache & Mars Ascent Vehicle
- Thermal Control:
  - CO2 gas gap insulation
  - up to 30 RHU's
  - Radiators & LHPs or Pumped Fluid Loop

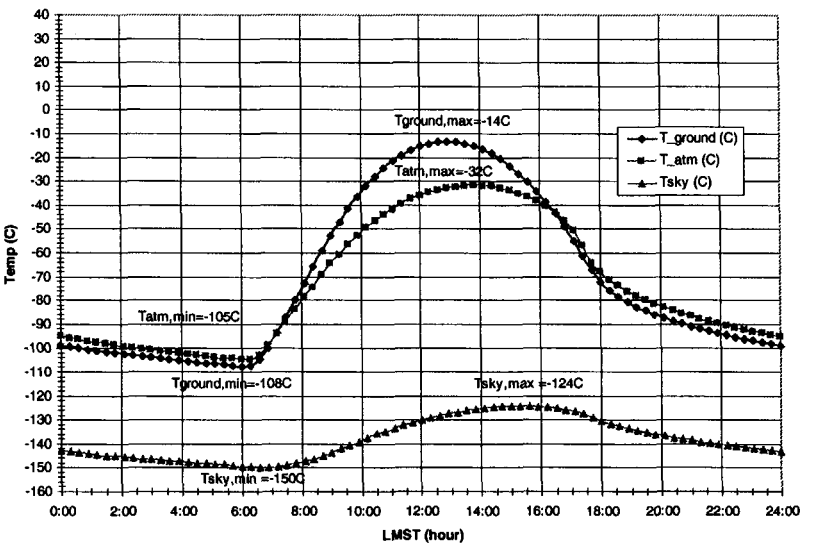


Worst-Case Hot and Cold Environment

MER Case 1A - Highest Max Daily Extreme (Rover & Lander) - Tau=0.2, albedo = 0.08, Ls=328, elev = -1.3km, inertia =170, lat = -15, MER1 Sol 0



MER Case 2A - Lowest Min Daily Extreme (Rover) - Tau=0.2, albedo = 0.34, Ls=16, elev = -1.3km, inertia =170, lat = -15, MER1, Sol 90



Thermal Control of Mars Surface Vehicles

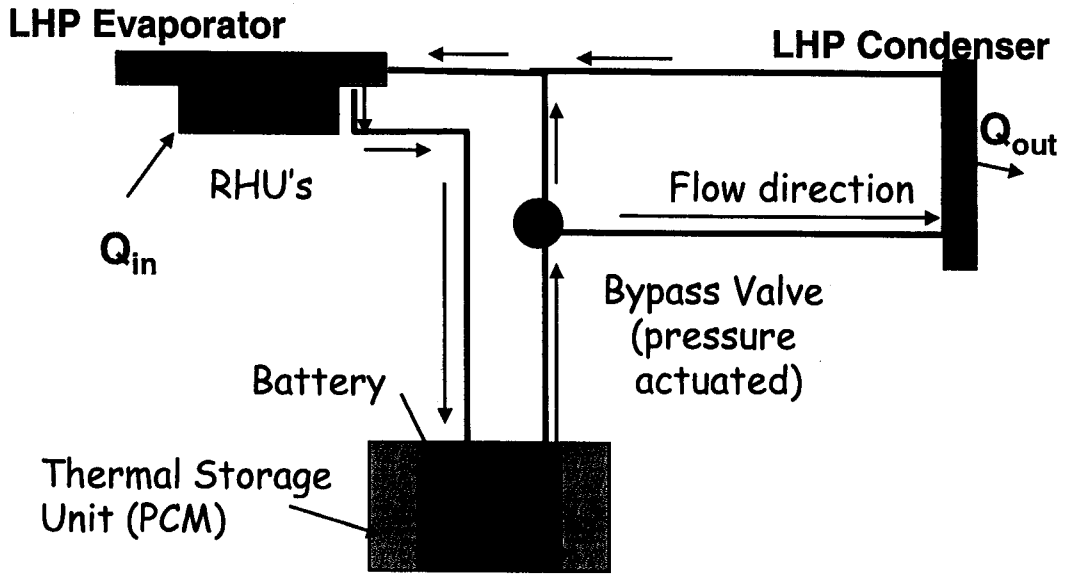
- The thermal control driver for rover/lander is to protect the electronics, batteries, and science from the cold night while being able to reject heat during the day. The key thermal control element needed is thermal switch
- Mars missions in the past have used passive thermal capacity or a gas-gap heat switch
  - Viking (passive heat switch), Mars Pathfinder (passive thermal capacity), Mars Polar Lander (passive Thermal capacity), MER rover (passive wax actuated heat switch).

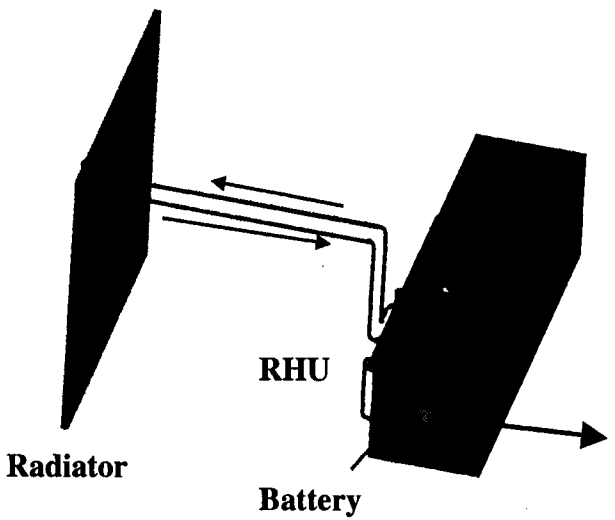
Technology / Attributes	Mechanical Heat switch	Loop Heat Pipe (LHP)	Mech. pumped Cooling Loop
Heat transfer cap., W	1 to 20	10 to over 100	25 to over 250
Flexibility	Not flexible	Flexible and long life reliability	Flexible and robust, long life issues
Heat collection/rejection flexibility	Constrained to small foot print	Constrained for collection, none for rejection	No constraints
Typical mass (kg) and power (W)	0.1 to 0.12 None	0.3 to 0.5 1 for "off" and 5 for start up (few minutes)	4 to 20 5 to 10 for ON None for OFF
Conduction, W/K, ON OFF	0.4 to 0.5 0.02 to 0.025	Up to 15 0.02 to 0.03	5 to 10 0.03 to 0.05
Heritage and applications	Medium, component level	Good, component and S/C	Medium, component & S/C

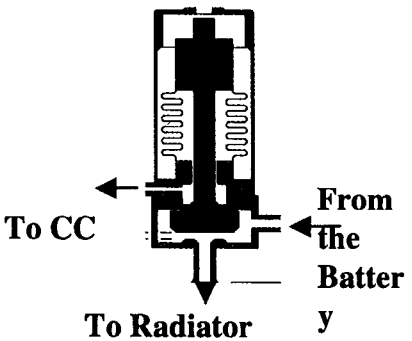
Advantages of Mini loop Heat Pipes

- Mini loop heat pipes are typically have wick size of $\frac{1}{2}$ inch diameter or less and transfer lines of diameter 1/16 to 3/32 inch
- The mini LHP investigated had aluminum evaporators and SS transfer lines and condensers, and either nickel or titanium wicks
- Mini LHPs are light and compact for a heat transfer range of 10 to 100 Watts LHP have high capillary head capacity to overcome Mars gravity conditions
- They are efficient since they combine heat transfer and heat switch functions in one device, further source temperature can be controlled
- Transfer lines are flexible and can be easily routed easily in the restricted space of the rover and lander. Coils in the lines allows limited deployment of the radiators
- Because of the thin SS condenser lines, they can easily withstand limited number of freeze/thaw cycles (about 100 cycles)

Variable Conductance Mini Loop Heat Pipe



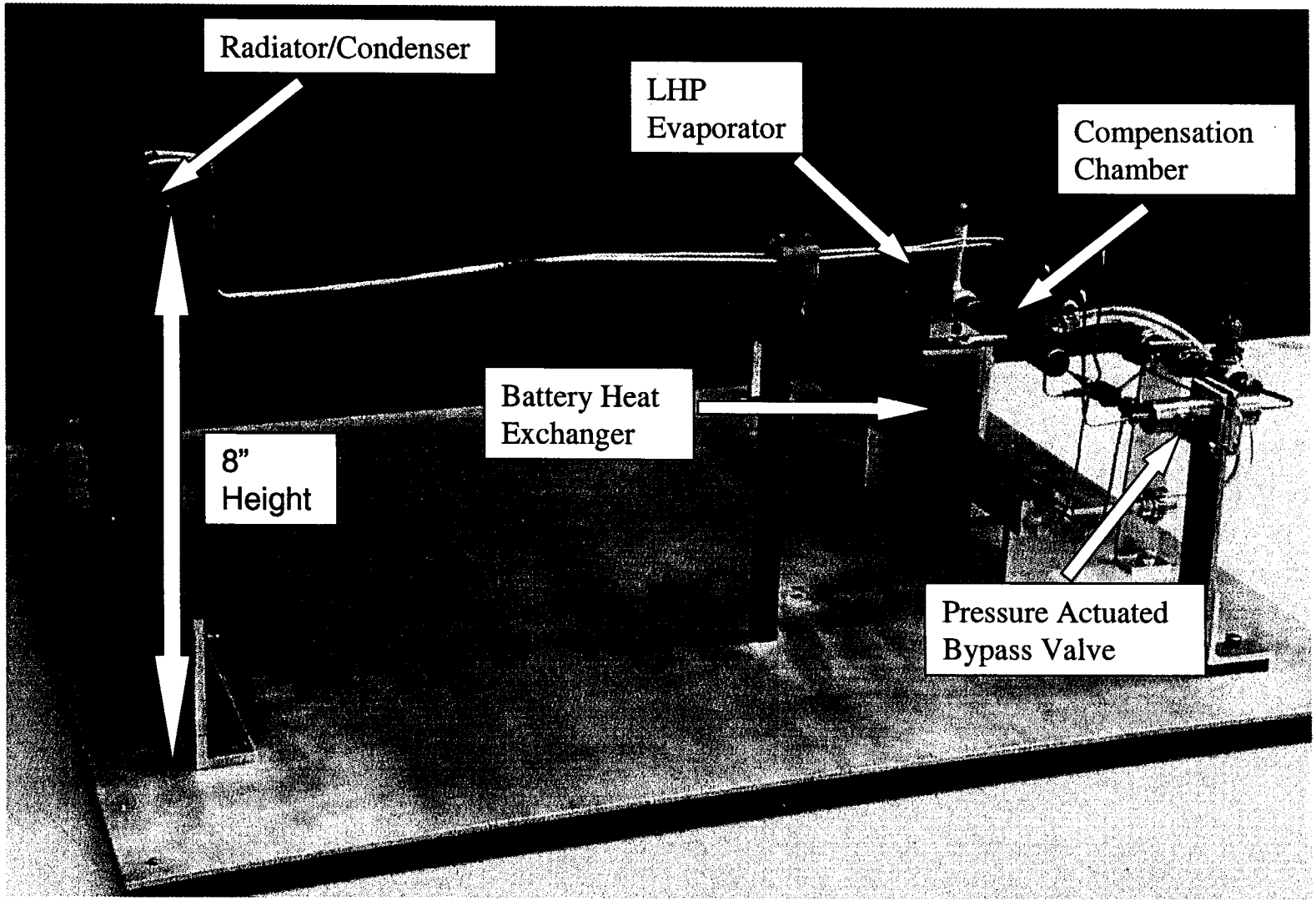




Application

- VCLHP evaluated for Mars battery thermal control
- Backpressure actuated valve is used to bypass the radiator
- Small dia (1/16") tubing allows the condenser to freeze and thaw during Martian diurnal cycles
- Performance and condenser freeze/thaw tests (100 cycles) conducted during late 2000

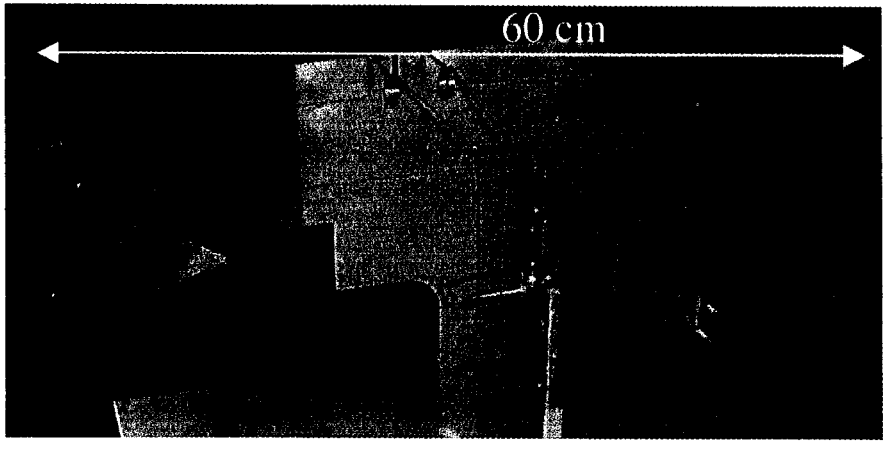
Variable Conductance Loop Heat Pipe



Summary of Mini VCLHP Investigation

- A mini LHP with bypass valve was investigated during 1999-2000 for the Li-ion battery thermal control on Mars rovers
- The mini VCLHP with nickel wick performed well above 10 W of heater power; for heat loads of under 10 W, the start up and steady state temperatures were not consistent
- The mini VCLHP with titanium wick started consistently at 6.5 W; the by-pass valve performance was not consistent below 10 W; at heat loads of over 30 W the valve performance was more consistent
- Mini VCLHP with titanium wick was tested without the by-pass valve, and it performed well with 6.5 W heat load with start-up heaters (3.5 W) on the evaporators and shut-off heaters on CC heater (1 to 3.2 W)
- Presently investigating thermal control valves that can provide better performance for the VCLHP at low heat loads (under 10 W)

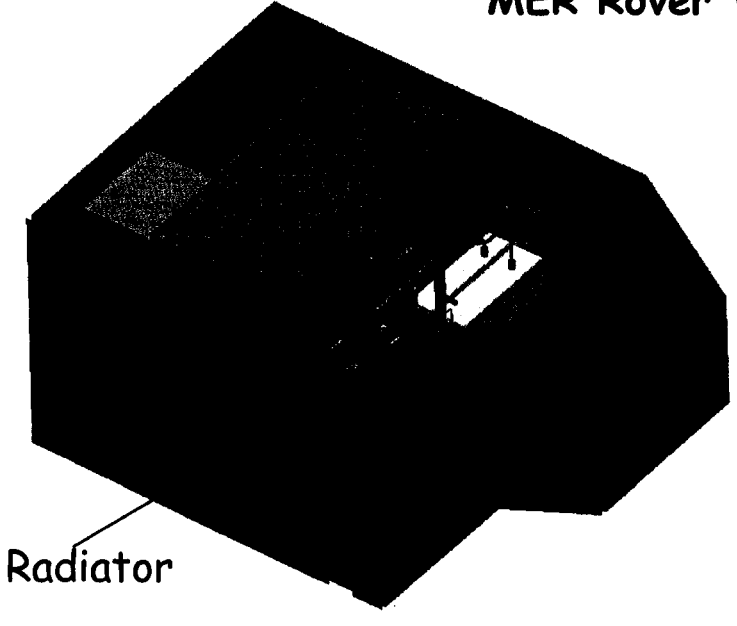
MER Rover Miniature Loop Heat Pipe



Description

- Mini loop heat pipe with 0.5 inch nickel wick and ammonia as working fluid
- Light weight (less than 150 gms with out the radiator to transfer 50 W)
- Vapor and liquid lines are 1/16 inch dia provides enormous flexibility in locating heat sources and sinks on the spacecraft

MER Rover WEB



Application

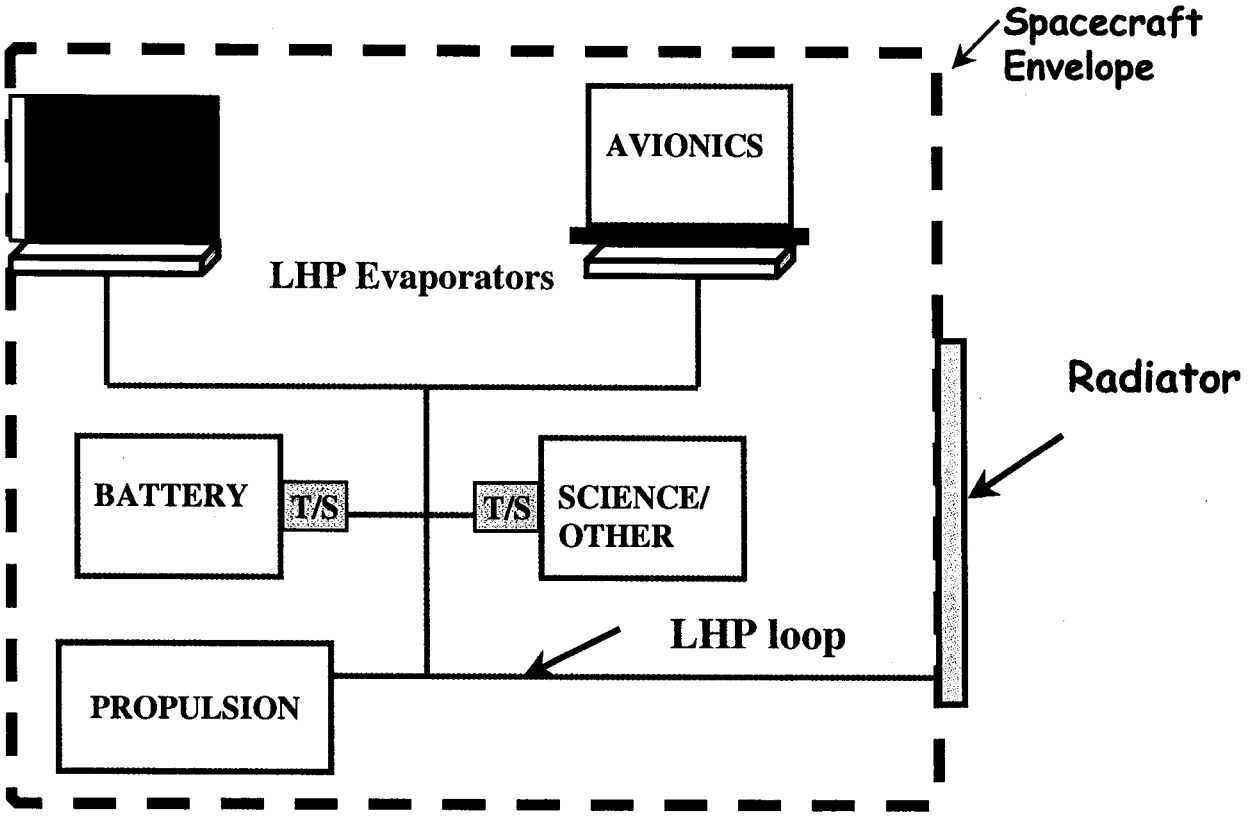
- This LHP removes heat from the MER rover SSPA during the day on Mars, start up heater and CC heater used for control
- Light weight and flexibility allows for easy mechanical integration in the rover
- Small dia tubing allows the condenser to freeze and thaw during Martian diurnal cycles

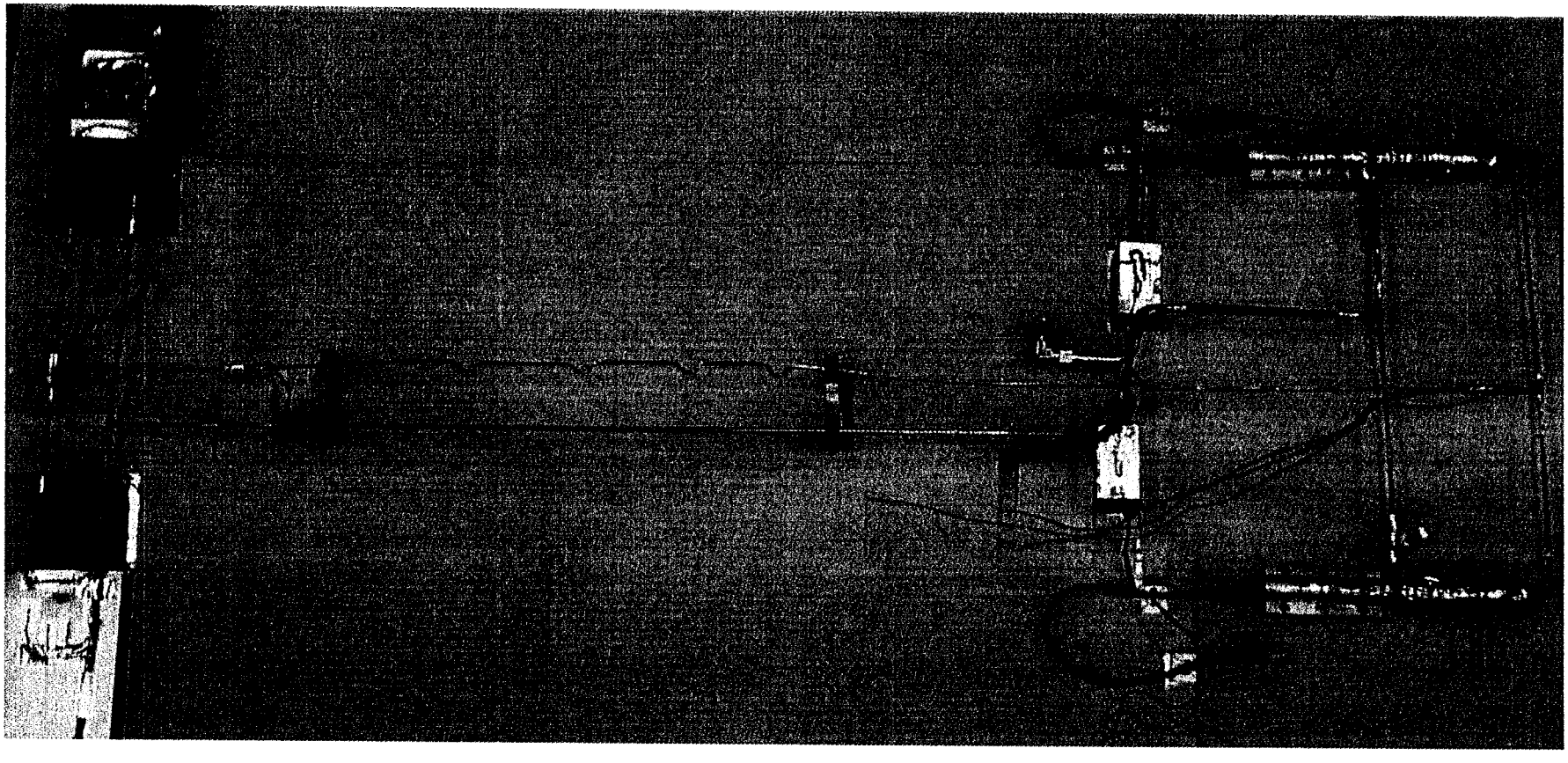
Summary of Mini SSPA LHP Investigation

- The mini LHP was investigated for the thermal control of telecom (SSPA) equipment on the MER rover to remove up 50 W of heat load
- Start-up heater on the evaporator (5 Watts) and a shut-off heater on the CC (1 W) were used for starting and stopping of the LHP.
- The mini LHP underwent freeze/thaw cycles over 100 (-120 to +40 C) to verify its integrity during Martian diurnal cycles. (more on this in Mike Pauken's presentation)
- The test showed that the mini LHP meets all the requirement of the MER rover SSPA thermal control requirements, however it was taken out of MER rover as part of the mass reduction exercise in late 2001.

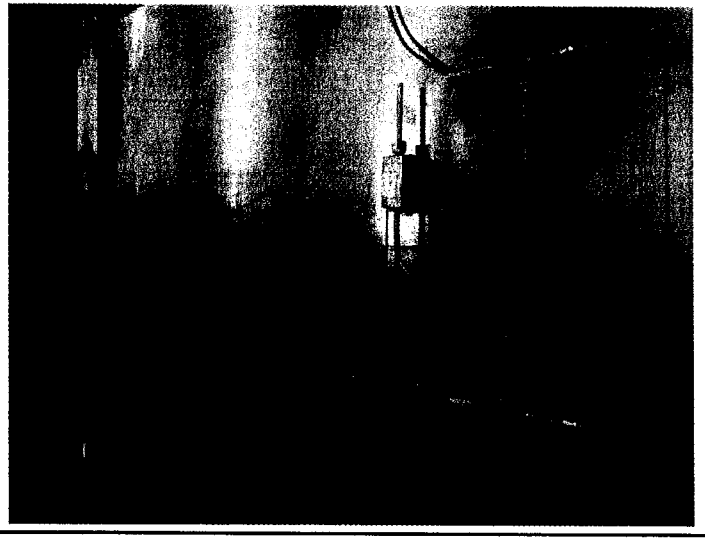
Advanced Thermal Architecture

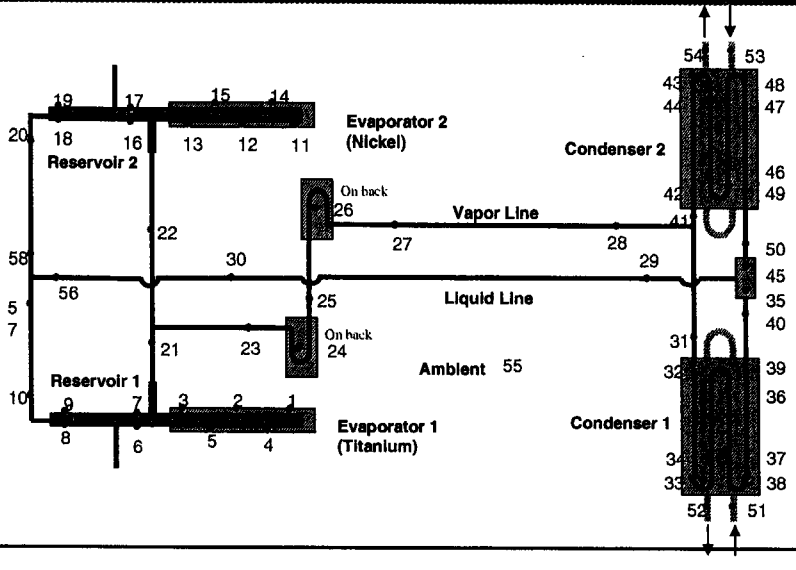
Based on mini LHP





Dual Miniature Evaporator Mini LHP





Participants & Facilities

- JPL is investigating this technology for space applications (Mars rover & microspacecraft)
- Tests performed at GSFC during FY00 and more tests at JPL in 2001 for its applications for passive thermal control architecture
- Dynatherm Corporation fabricated the dual evaporator (Ni and Ti wicks) miniature loop heat pipe

Mission Impact & Future Applications

- This technology reduces S/C thermal control mass and provides enormous flexibility
- This is a key technology for enabling Integrated Thermal Energy Management System
- This technology is applicable to small & large S/C and planetary vehicles thermal control

Conclusions

- Mini loop heat pipes provides an important thermal control function for Mars rovers and landers
- Start-up and shut-off operation of LHPs show that CC heaters and start up heaters can ensure safe operation
- Freeze-thaw cycles show that mini LHP's can be safely used for 100 sol mission
- Advanced features such as control valves and dual evaporators show that mini LHPs can be more versatile