Loop Heat Pipe Applications for Thermal Control of Martian Landers/Rovers

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OUTLINE

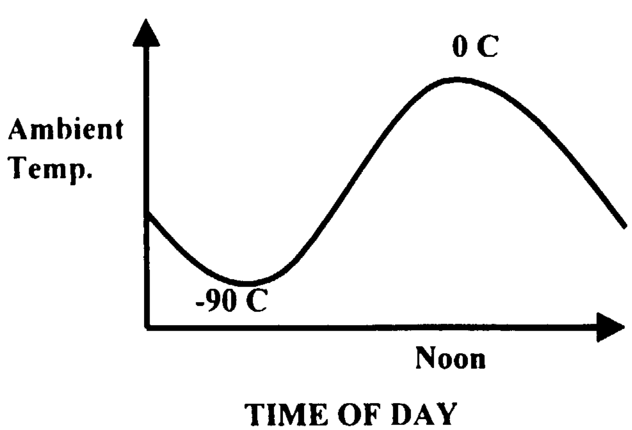
- Background of Mars Program
- Thermal Control Design for Martian spacecraft
- Loop Heat Pipe for Lander and Rovers
- Test Results
- LHP Applications for Future Martian Landers and Rovers

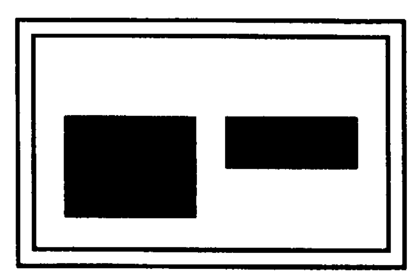
Background

- In early nineties Mars was designated as the planet to be explored the internationally space agencies
- Mars Pathfinder was launched in December 1996 by JPL/NASA to put a lander and a microrover on Mars on July 4, 1997
- Mars Polar Lander was launched in ~~December~~ January 199~~8~~9 by JPL/NASA to put a lander on Mars in late 1999 (built by Lockheed Martin)
- Mars Surveyor Program will be launched in 2001 to put a lander and a microrover on Mars in 2002
- A lander and a rover would be sent in 2003 and 2005
- Several other Mars missions are being planned (Mars Micromissions)

Thermal Control Design
(Key Drivers)

- To keep the equipment above the low temp limit in a warm enclosure during the nighttime Martian surface operations (-90 C environment)
- Minimize heater power at night to reduce load on the battery power
- To keep equipment upper temperature limit during day time operations on Mars
- Able to transfer 50 to 100 W of heat from lander and about 7 W from rover during cruise
- All this point to an efficient thermal switch in the thermal design





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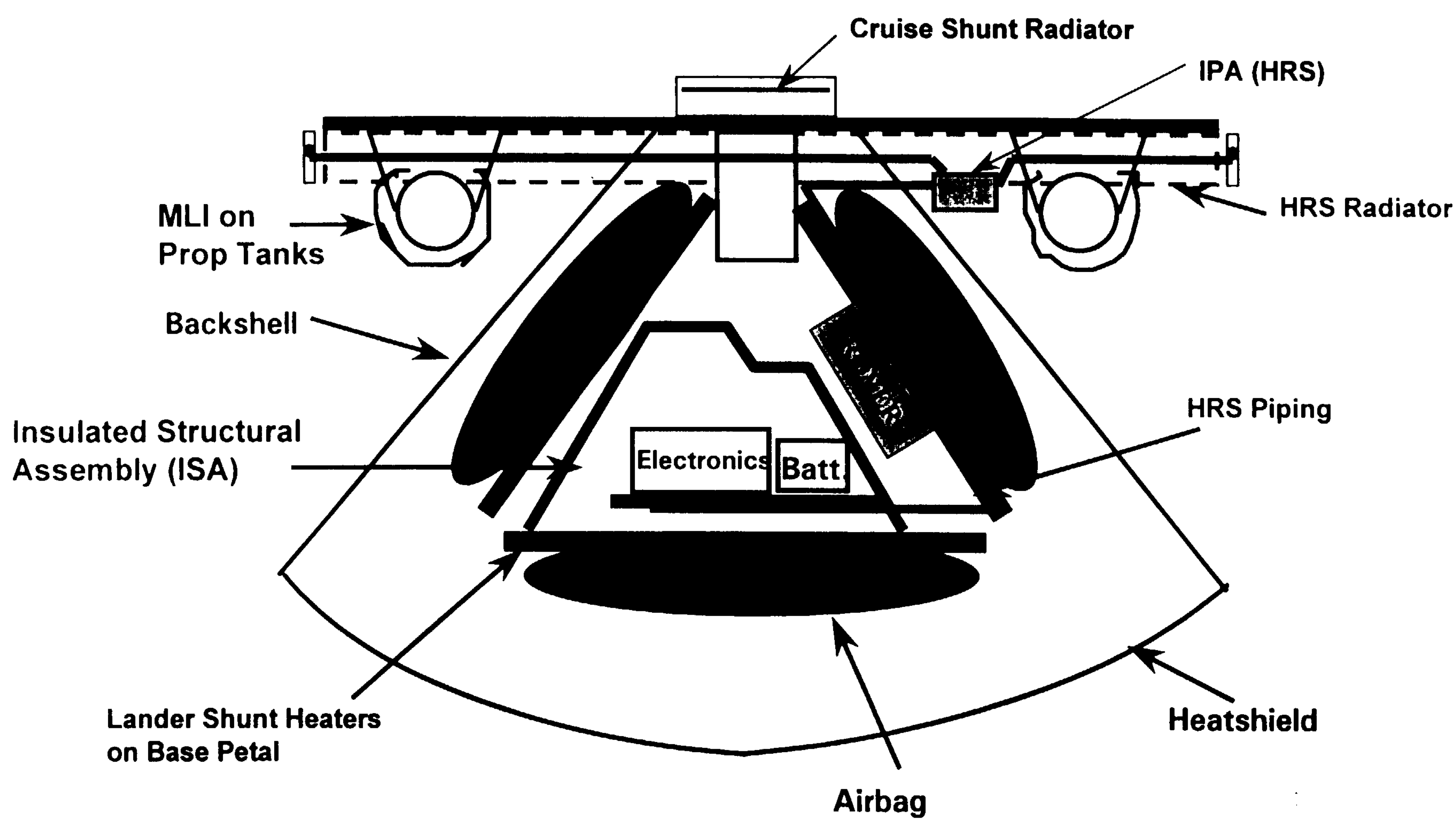
Thermal Environment for Martian Landers and Rovers

- **Cruise Conditions:**
  - Thermal environment is -20 to 30 C for both lander and rover
  - Lander power level in the 50 to 100 W range
  - Rover power level around 7 W (RHU thermal power)
- **Martian Landed Conditions:**
  - Thermal environment is -90 to 0 C
  - Lander hot conditions: 50 to 100 W; 0 C environment and solar loads
  - Lander cold conditions: 5 to 10 W; -90 C environment and cold sky
  - Rover hot conditions: 20 to 40 W; 0 C environment and solar loads
  - Rover cold conditions: 7 W; -90 C environment and cold sky

Mars Pathfinder and MSP Lander Thermal Control

- Pathfinder (1996) needed to reject heat during cruise and conserve heat on cold Martian surface
- Mechanically pumped single-phase liquid cooling used as the heat rejection system for lander during cruise; passive thermal control on Mars
- Rover used a cold finger of the spacecraft cooling loop during cruise and passive thermal control on Mars
- Mars Polar Lander (Mars '98) uses passive thermal control during both the cruise and landed operations
- Mars '01 rover is planning on using an external heat pipe to reject heat during cruise and passive thermal control on Mars
- Mars '01 Lander thermal control is being designed; probably passive during both cruise and landed operations
- Mars Exploration Technologies Program is investigating LHP as part of rover battery thermal control

Mars Pathfinder Spacecraft Layout (Thermal)



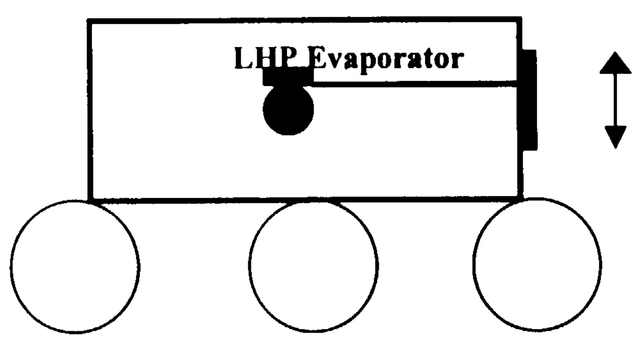
Active Cooling Loops vs Passive Cooling Loops

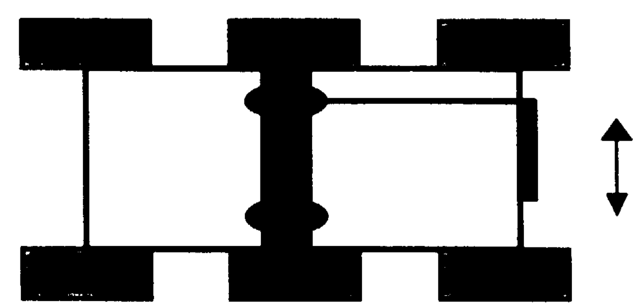
- Active Loops:
  - Mechanical pumps circulating single-phase fluid between source and sink
  - Gravity insensitive, can use mechanical joints, can handle large powers
  - Can collect and reject heat from wide surface areas, excellent flow control
  - Demonstrated flight heritage of 8 months and ground life of 20 months
  - Requires: electrical power (10 W to remove 150 W heat), electronics for motor control, accumulator

- Passive Loops:
  - Based on two-phase based heat pipes such as loop heat pipe
  - Can function in adverse gradients (several meter high), can reject heat over large areas, no electronic controls needed
  - Demonstrated flight heritage of ~~of~~ over 8 years (Russian S/C)
  - The whole unit is welded and sealed, heat collection is limited to the evaporator foot print, limited heat transfer capacity due to passive nature,

Need for Dual Compensation Chamber LHP for Mars

- LHP works in adverse gradients with the condenser above the evaporator
- Single CC LHP restricts the CC to be at or above the evaporator in gravity environment due to weaker secondary wick
- There is a need for dual CC LHP for Mars lander/rover since their orientations on Mars are not predetermined





Dual Compensation Chamber LHP for Mars Application

- The objective was to fabricate a dual CC to an existing LHP design and evaluate it Mars lander and rover applications

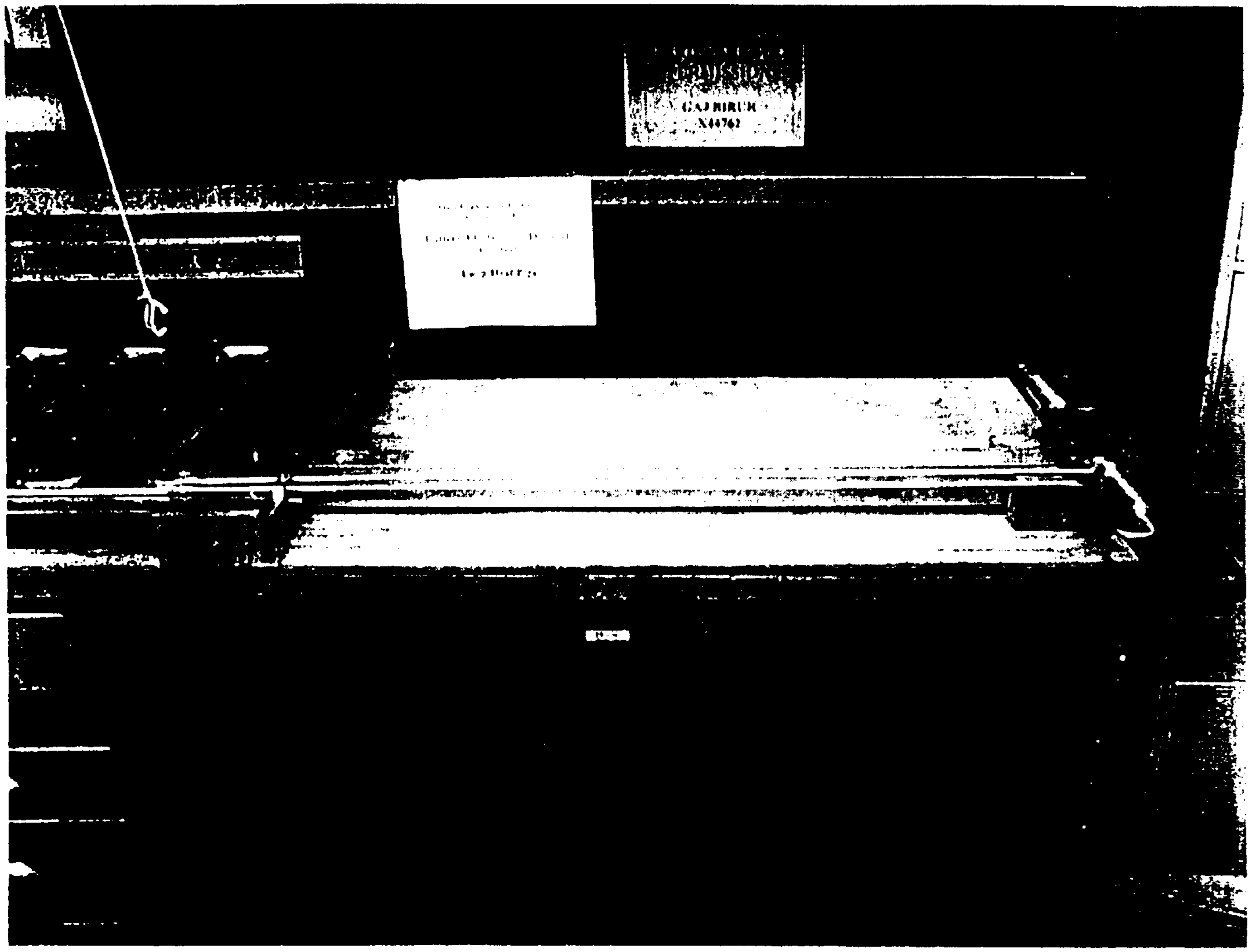
- **Specifications**:
- Evaporator: Aluminum 6061, 0.95 ID, 6" long
- Primary Wick: Sintered Nickel, 1.2 micron pore size, porosity 0.6, Permeability 4X10-14 m2
- Comp. Chamber: Aluminum 6061, Volume 115 cm3
- Transport lines: Aluminum 6061 tubing, 1/4" X 0.035 Wall
  Vapor line - 38.4" long; Liquid Line - 46.1" long
- Condenser: Aluminum 6063 Extrusion, 0.157" ID X 149.8" long
- Working Fluid: Ammonia - 95.7 grams, 99.998% pure

Current Evaluation Objectives for Mars LHP

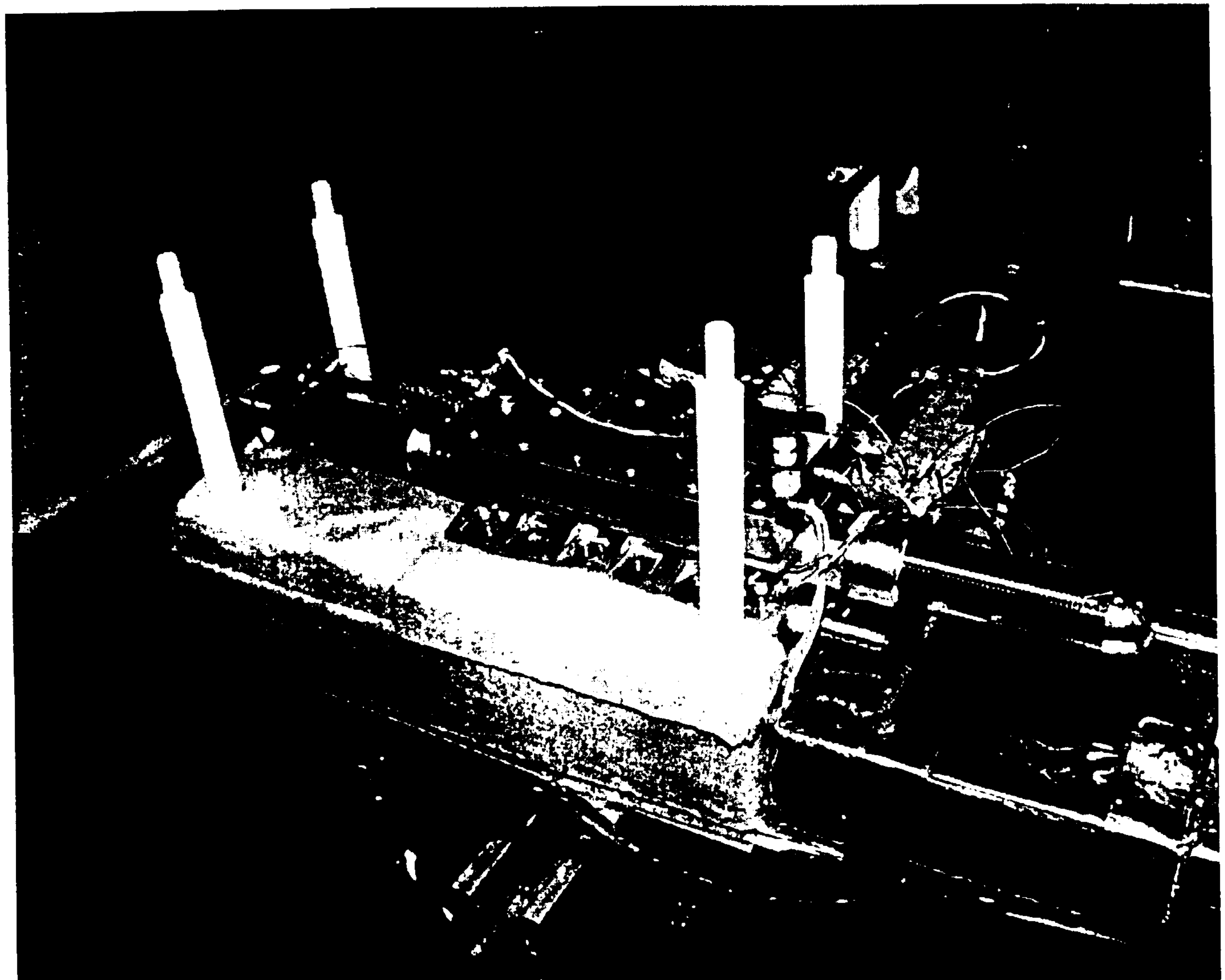
- Evaluate Dual Compensation Chamber LHP operation and Performance in gravity environment

  - Different CC orientation with respect to the evaporator
  - Different orientation of Evaporator with respect to the condenser
  - Evaporator temperature control with CC heater control
  - Transient performance under varying evaporator power
  - Transient performance during change in CC orientation
  - Start up power and low power operations

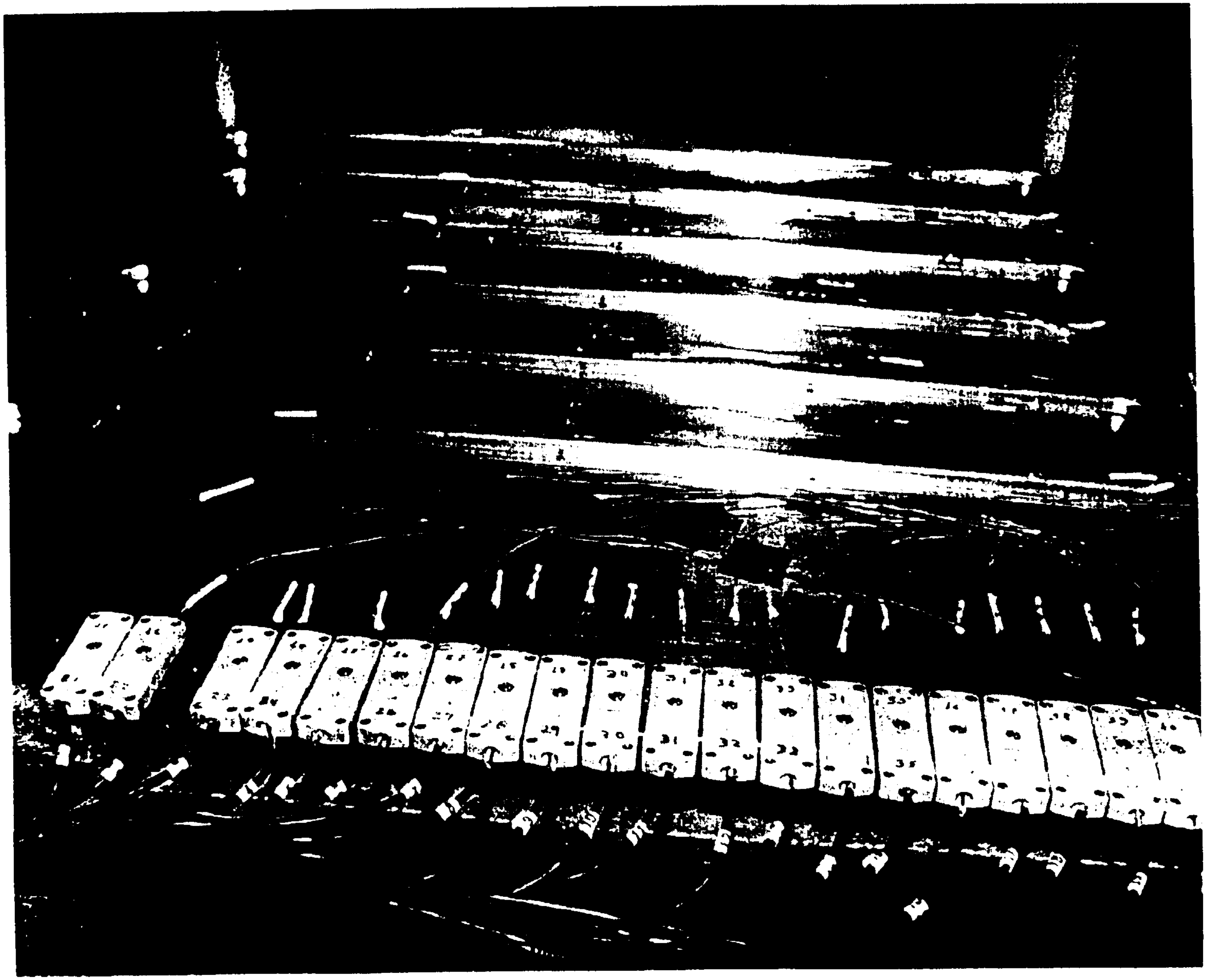
Dual CC Loop Heat Pipe



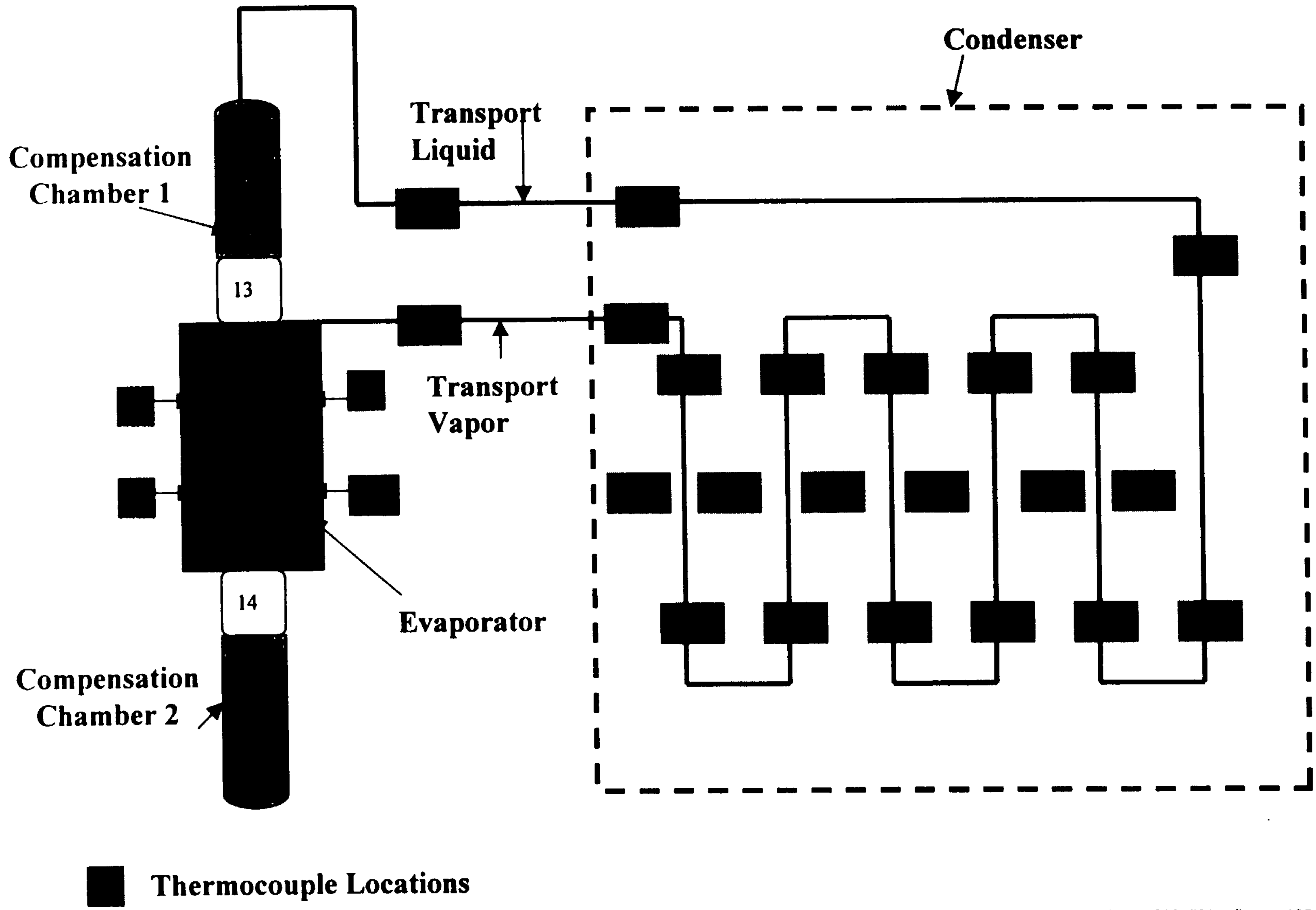
Dual CC LHP Evaporator on the Test Setup



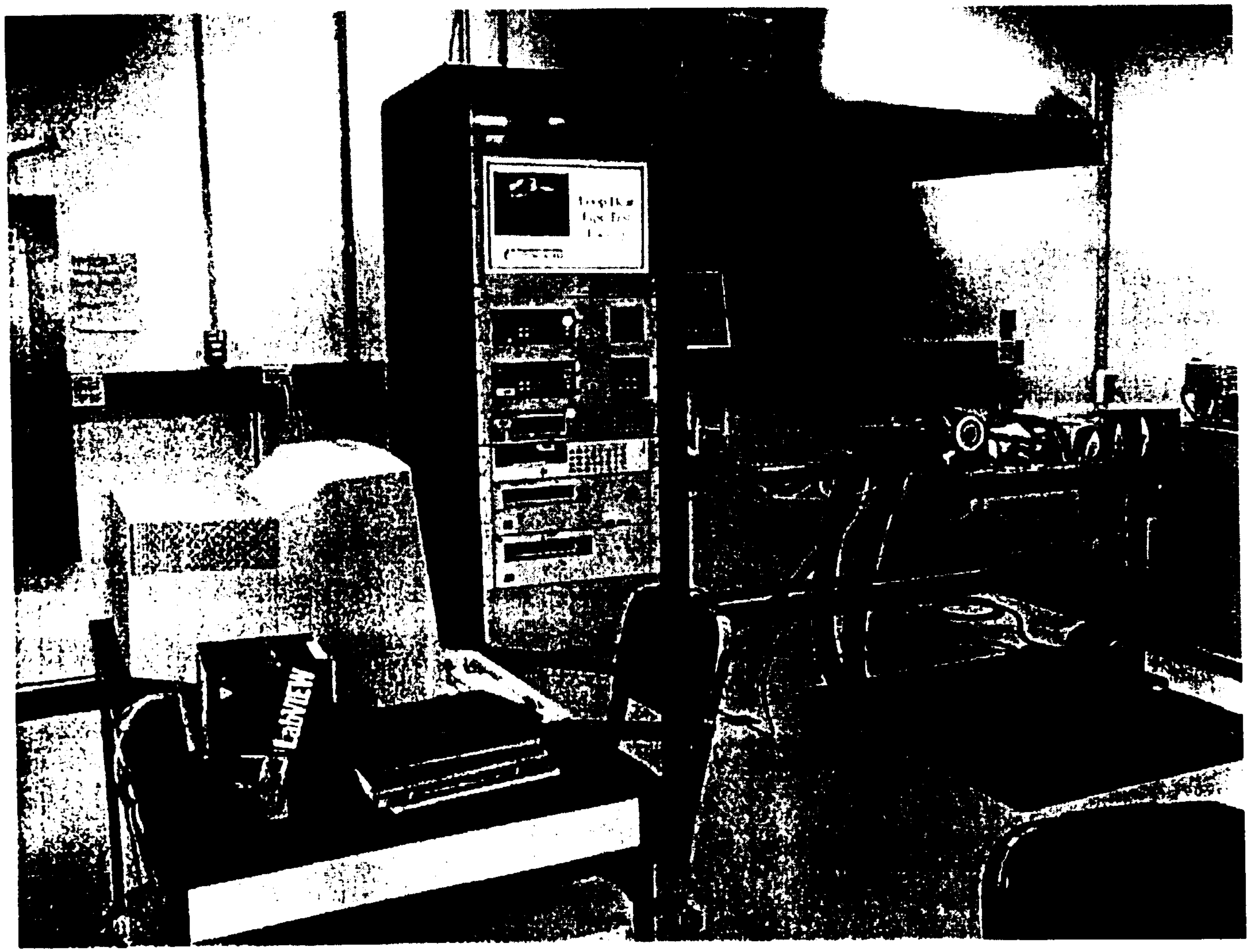
LHP Condenser Instrumentation



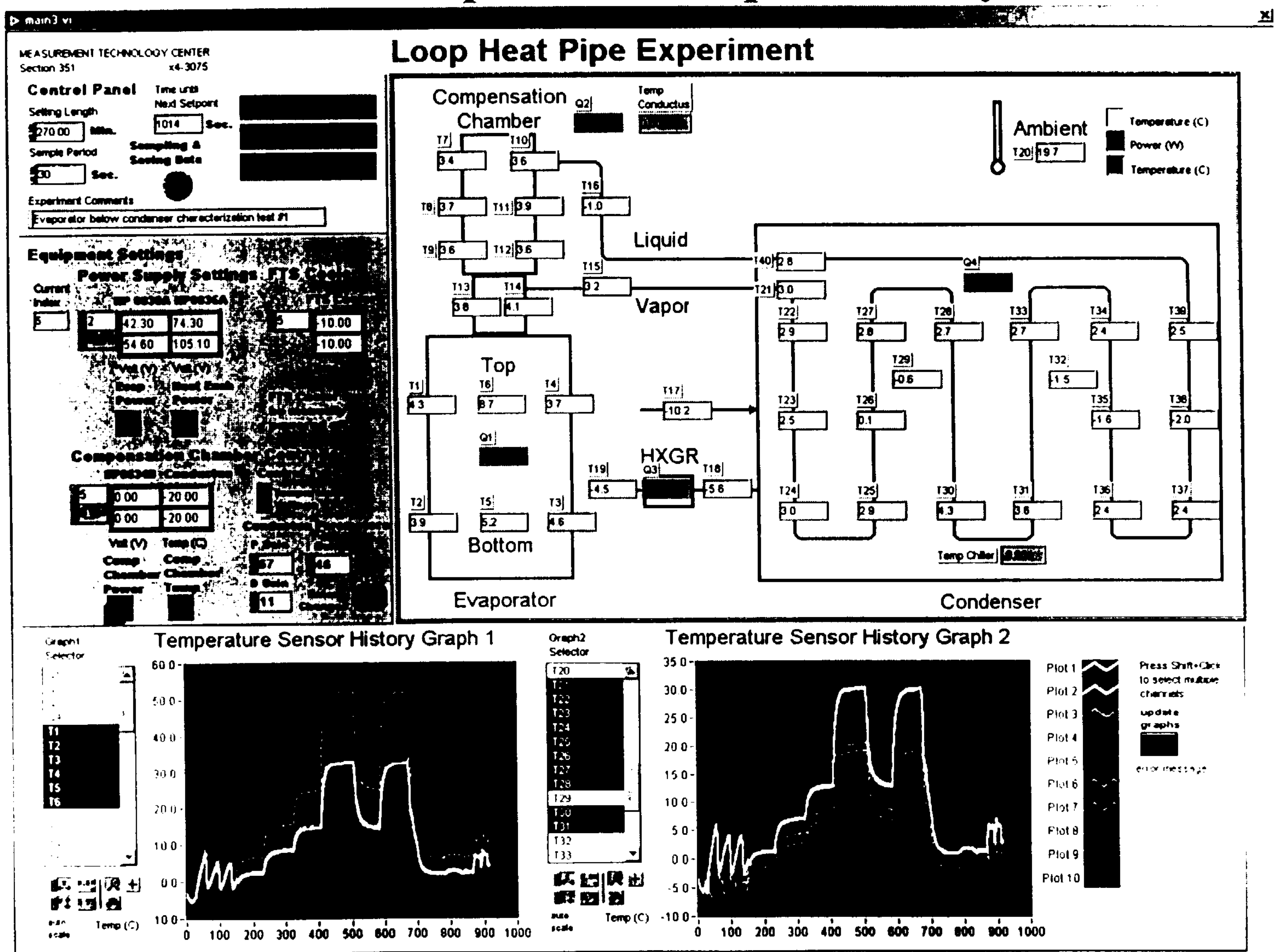
Double Compensation Chamber Loop Heat Pipe Test Setup



JPL Loop Heat Pipe Test Bed



LHP Test Setup - Data Acquisition System



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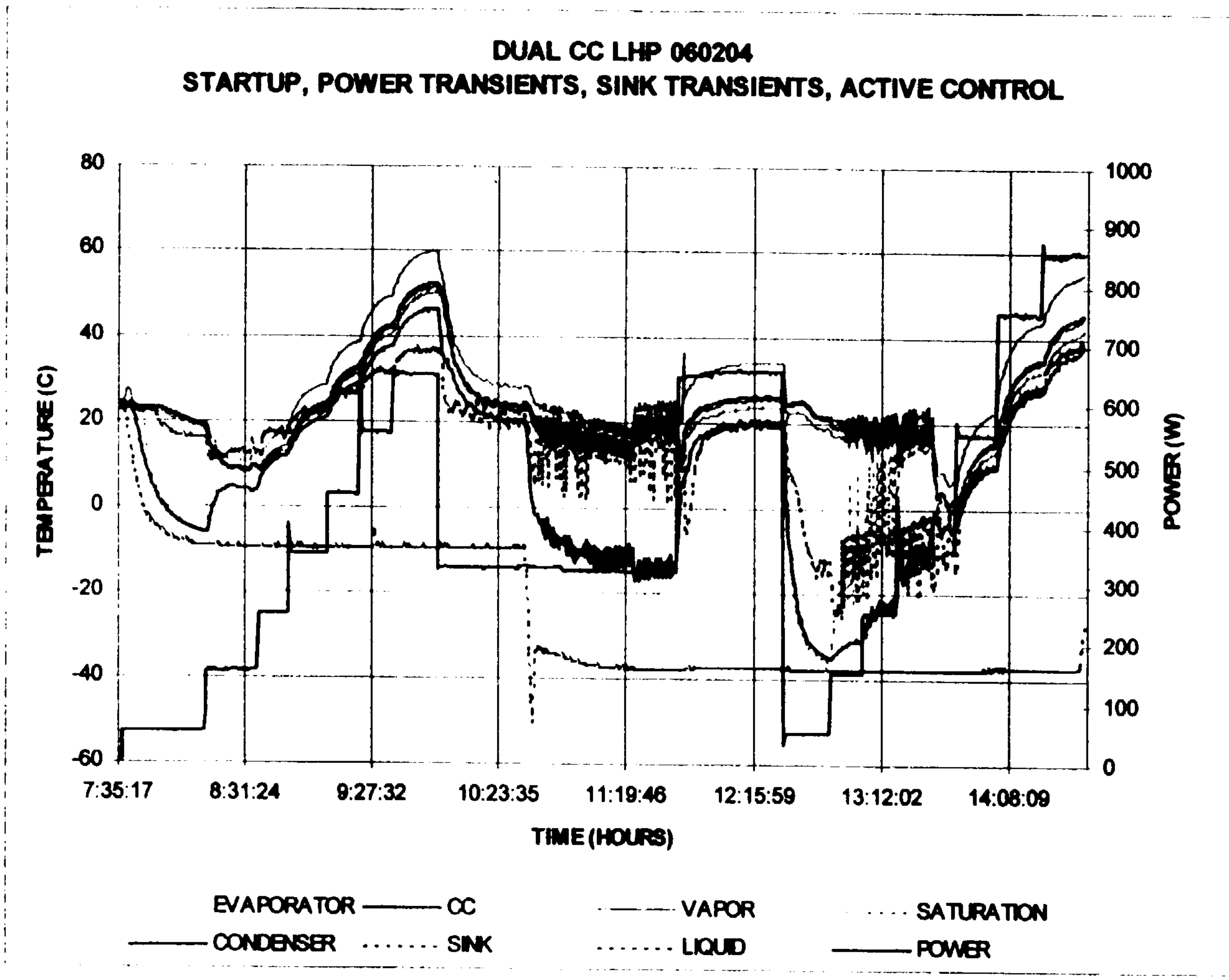
~~March 6, 1997; Gaj Birur~~

LHP Performance Profile

(for Startup, Power Transients, and Active Control)



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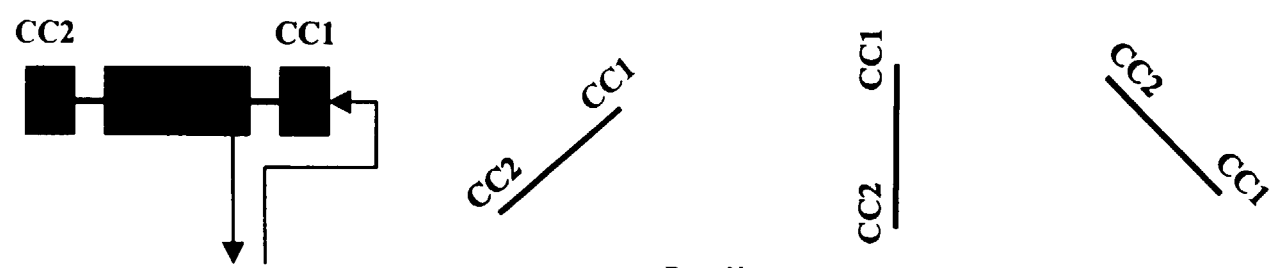
LHP Performance Test Data

(for Various CC orientations, and Evaporator Power Levels)

Evaporator Temp in C at different power levels; Sink at -10 C						
Config	**Power, W**	**50**	**150**	**250**	**350**	**650**
Hori/zero	CC1 at CC2	24	12	10	16	33
Horiz/neg45	CC1 below CC2	18	10		22	44
Horiz/neg90	CC1 below CC2	16	8		22	46
Horiz/pos45	CC1 above CC2	15	10		15-16	33
Horiz/pos90	CC1 above CC2	18,28	12	13	15/17	33-35
Vert/zero	CC1 at CC2	36	20	16	17	32
Vert/pos45	CC1 below CC2	26	15	16	22	43
Vert neg45	CC1 above CC2	25	14	13	16	29
Vert 180	CC1 at CC2	0-6	3	8	14	33



LHP Performance Test Data

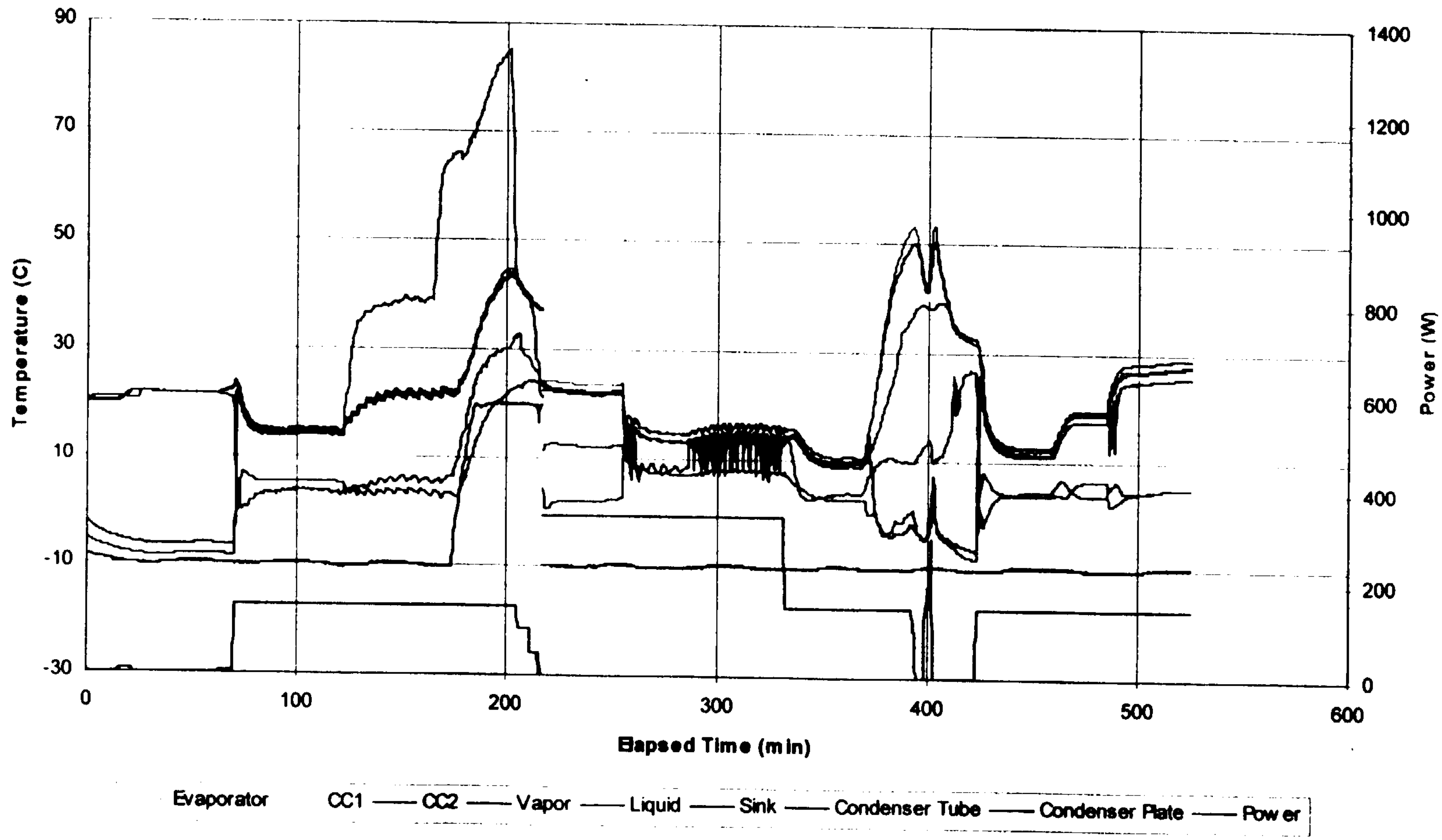
(for Various CC orientations, and CC Active Control)

- In Horizontal configuration with Sink at -40 C and Evaporator power of 325 W, a CC heater of 30 W takes the evaporator from 5 C to 20 C
- In horizontal configuration with the CC1 above CC2, with sink at -10 C and evaporator at 150 W, a CC heater of 5 W raises the evaporator from 15 to 22 C
- In vertical configuration with CC1 at same level as CC2 and sink at -10 C and evaporator at 150 W, a 10 W CC heater power raises evaporator from 15 to 22 C

LHP Performance Test Data

(for Change in Orientation during LHP Operation)

Startup, CC, and Transient Test for Vertical pos45 to neg45
(February 1, 1999)



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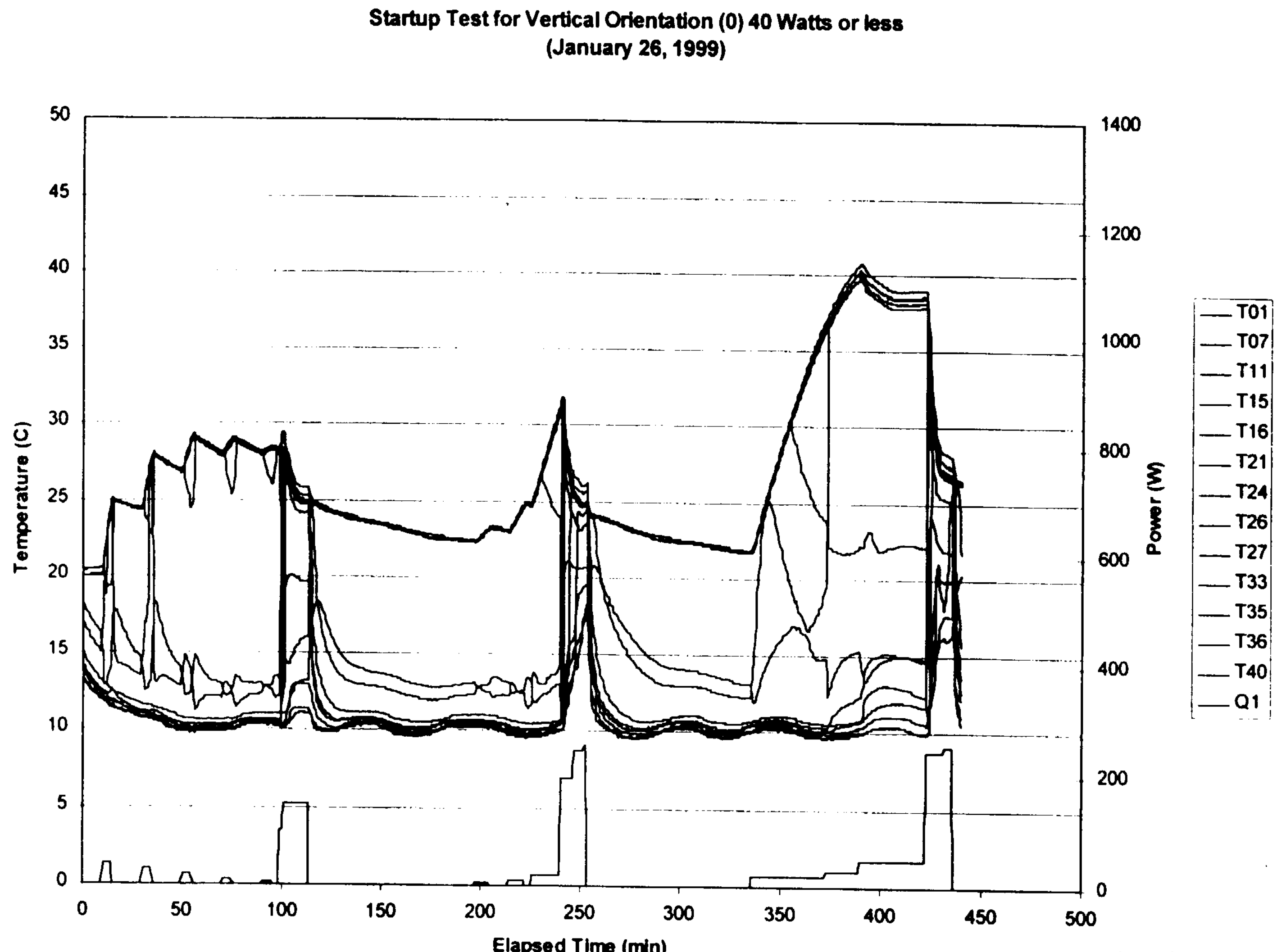
LHP Performance Test Data

(for startup power at different orientation)



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Conclusions

- The dual-chamber LHP functioned in all orientation of the compensation chambers with respect to the evaporator
- The LHP was operated over an evaporator heater power range of 50 to 650 W at sink temperatures of 10 C to -40 C
- The LHP starts at powers as low as 5W in all orientations
- The evaporator equilibrium temperature vary as much as 8 C at 350 W and 13 C at 650 W depending on the orientation of CC1 and CC2
- Evaporator temperature oscillated about 8 C at low powers (50 W) for some orientations
- At low powers of 50 W, the equilibrium evaporator temperature varied as much as 10 C for one orientation (CC2 below CC1)

Future Work in LHP Applications to Martian Landers/Rovers

- Low mass Miniature Loop Heat Pipes of 10 to 60 W capacity
- Mechanical integration of LHP with Phase Change Material thermal storage for rover battery thermal control
- Use of working fluids such as propylene for low temperature operation (below -80 C)

Presenters Introduction

- Gaj Birur -
  - Gaj is a Senior Engineer in the Thermal and Propulsion Engineering Section at JPL where he has been working for the last nineteen years. His current areas of interests are spacecraft thermal control design, thermal hardware implementation, and advanced thermal technologies for future deep space spacecraft and Martian landers and rovers.