Novel Thermal Control Approaches for Mars Rovers

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

March 1-3, 2000

Presented at
11th Annual Spacecraft Thermal Control Technology Workshop
The Aerospace Corporation, El Segundo, California

OUTLINE

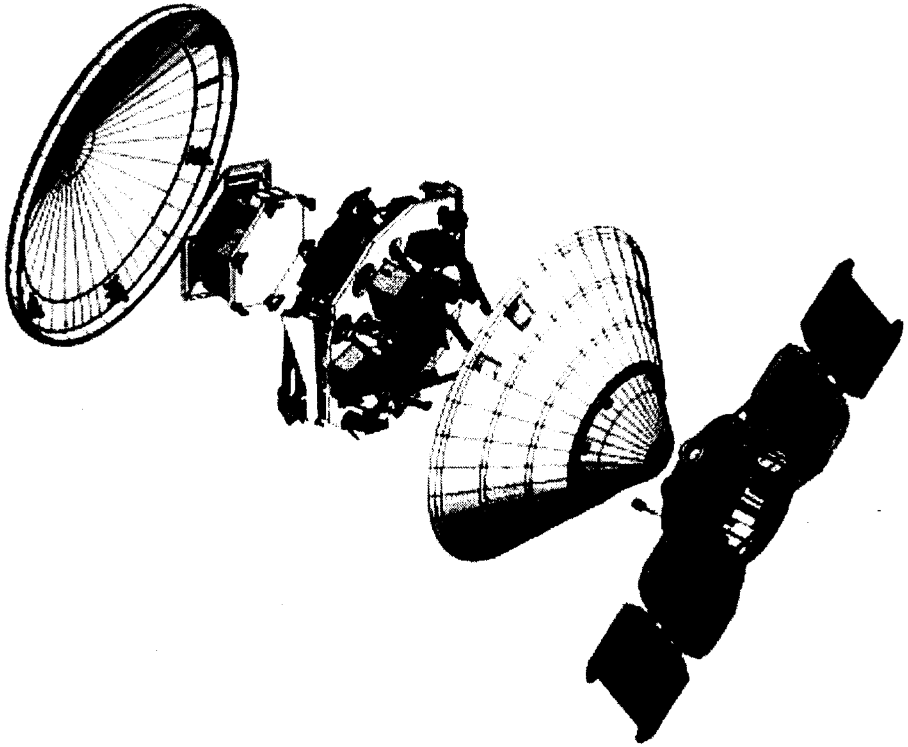
- Recent Past and Future NASA Landed Missions to Mars
- Thermal Control Requirements of Landed Mars Missions
- Advanced Thermal Control Technologies Needed
- Thermal Technology Development JPL
- Novel Thermal Control Approaches for Athena Rover
- Conclusions

Recent Past and Future NASA Landed Missions to Mars

- **Mars was designated as the planet to be explored cooperatively by the international space agencies in the early 1990's**
- **Mars Pathfinder, launched in December 1996 by JPL/NASA, deployed a lander and a microrover on Mars on July 4, 1997**
- **Mars Polar Lander, launched in January 1999 by JPL/NASA; lost during Entry/Descent/Landing on Mars in December 1999**
- **Since the loss of Mars Polar Lander, the entire future Mars exploration architecture has been under review including:**
  - Mars Surveyor Program (MSP), to be launched in 01, put a lander and a microrover (Marie Curie, 11kg) on Mars in 01
  - Mars Sample Return (MSR) Program to send lander/rover (Athena, 75kg) pairs in 2003 and 2005 and return soil/rock samples to Earth by 2008
  - Focus on In-situ missions, leading to robotic and human colonization missions

Thermal Requirements of Landed Mars Missions

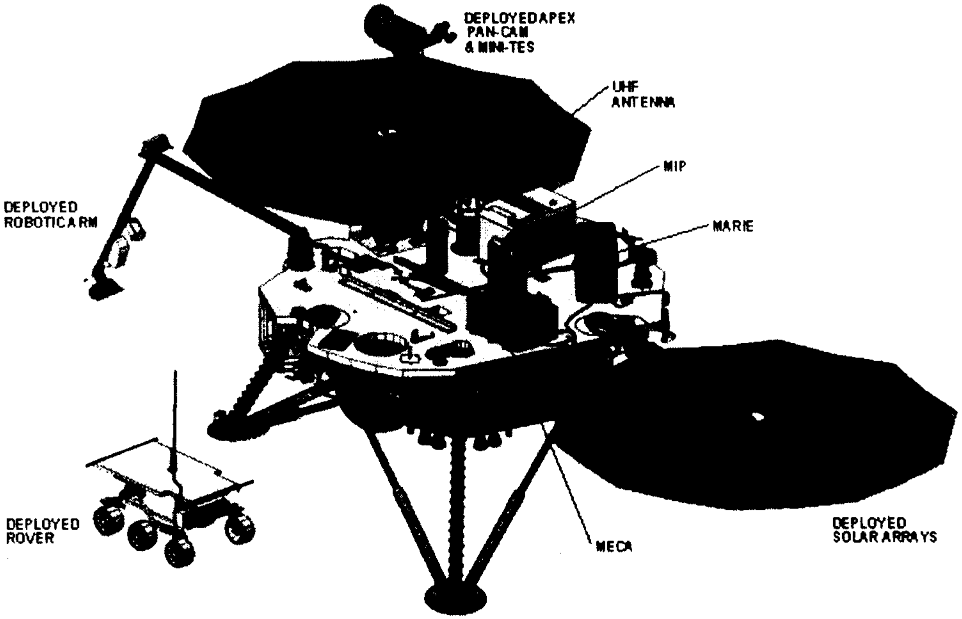
Mars '01 Lander
Cruise Configuration



- **Cruise Conditions:**
  - **Thermal environment is -70 (at Mars) to 30 C (at Earth) for both lander and rover**
  - **Lander power level in the 50 to 100 W range**
  - **Rover power level around 3 W (RHU thermal dissipation)**
  - **Vacuum (Insulation more efficient in vacuum)**

Thermal Requirements of Landed Mars Missions

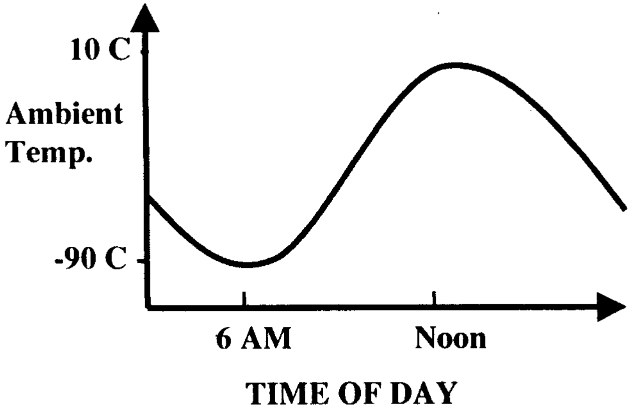
Mars '01 Lander
Landed Configuration

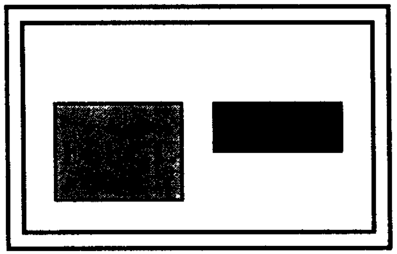


- **Mars Landed Conditions:**
  - **Sink temps: Atmosphere = -90C to 10 C, Ground = -100C to +30C, Sky = -130C,**
  - **Solar Insolation: up to 580 W/m^2 peak during day, 0 W/m^2 at night**
  - **Nighttime Internal Power dissipation: Lander = 20 to 30 W; Rover = 3W**
  - **Daytime Internal Power dissipation: Lander = 50 to 100W; Rover = 20 to 40 W**

Thermal Control Design - Key Drivers

- Transfer 50 W to 100 W of heat from lander and about 3 W to 7 W from rover during cruise
- Keep the equipment above the minimum survival temp limit (battery limit = -20C) in an insulated enclosure during the Martian night (-90 C env't.)
- Minimize survival heater power at night to reduce load on the battery
- Keep equipment below max temperature limit (battery limit = 30C) during daytime operations on Mars
- CONCLUSION: Thermal design needs a high performance insulation, a compact thermal storage device and a heat rejection radiator with an efficient thermal switch





MARS LANDER/ROVER
INSULATED
ENCLOSURE

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JPL Novel Approaches to Mars Rover Thermal Control

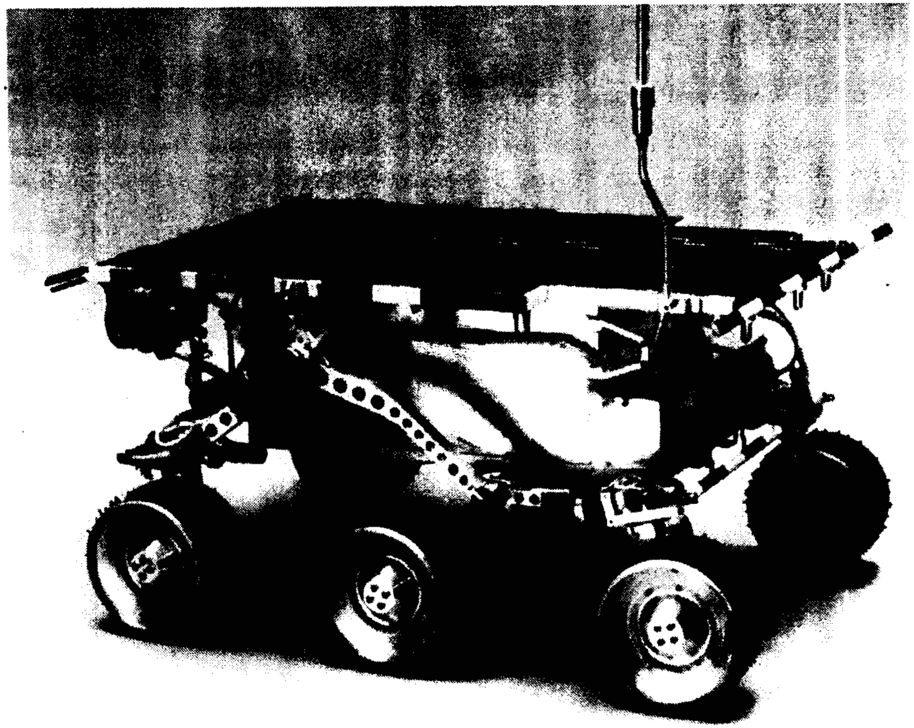
- **Lightweight, high-performance insulation**
  - Aerogel insulation, CO2 gas gap (details in Gaj's presentation)

- **Compact thermal storage**
  - dodecane wax, phase change material (0.06W*hrs/gm)
  - trade off against RHU (0.20 W*hrs /gm)

- **Thermal switches & heat transport devices**
  - **Heat switch**
    - Gas-gap, Wax actuator, LHP w/cc heater
  - **Variable conductance LHP**
    - LHP with bypass valve and PCM storage
  - **Mechanically pumped cooling loop**
    - currently being considered for the "Mega" rover (mobile mass = 750 kg)

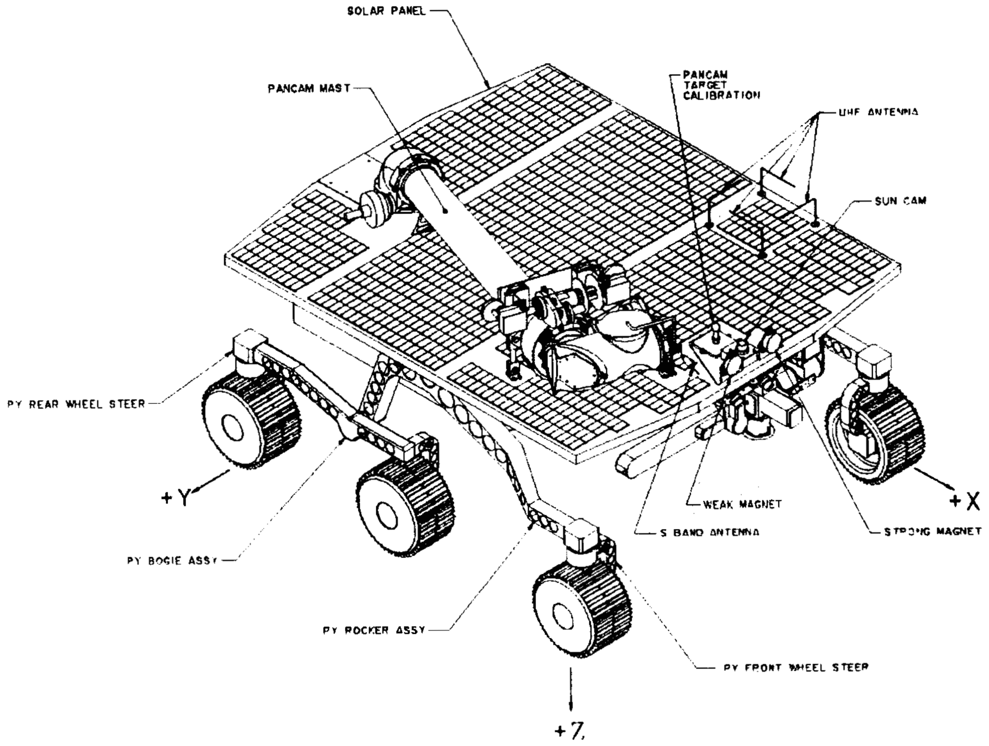
Mars Pathfinder Sojourner Micro-Rover

- Mass = 11.5kg (25 lbm)
- Solar Array = 0.25 m^2 (2.7 ft^2)
- Wheel diameter = 12 cm (5 in)
- Max Power = 15W
- Primary Battery
- Design Life = 30 days
- Telecom link to lander
- Payload: APXS & cameras
- Thermal Control:
  - Aerogel insulation
  - 3 RHU's
  - Internal mass



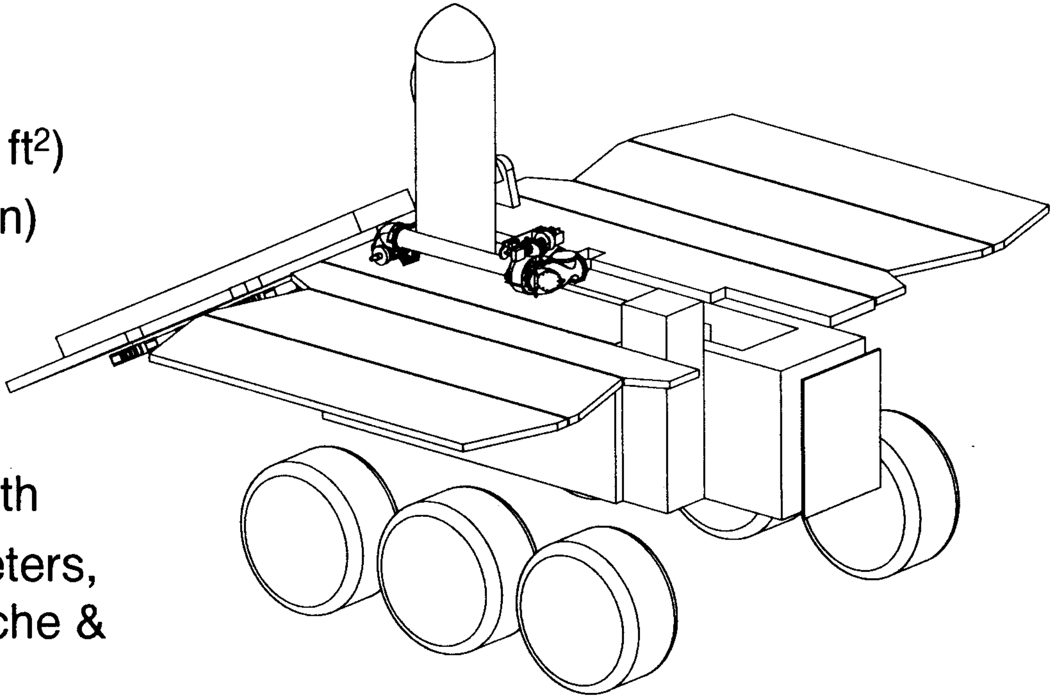
Mars Sample Return Athena Rover

- Mass = 75 kg (165 lbm)
- Solar Array Area = 1.4 m^2 (15 ft^2)
- Wheel diameter = 20 cm (8 in)
- Max Power = 75 W
- Secondary Battery
- Design Life = 90 days
- Telecom links to lander & orbiter
- Payload: cameras, spectrometers, instrum. arm, drill & sample cache
- Thermal Control:
  - Reinforced Aerogel or CO2 gas gap insulation
  - 5 to 7 RHU's
  - Radiator & Var. Cond. Mini LHP



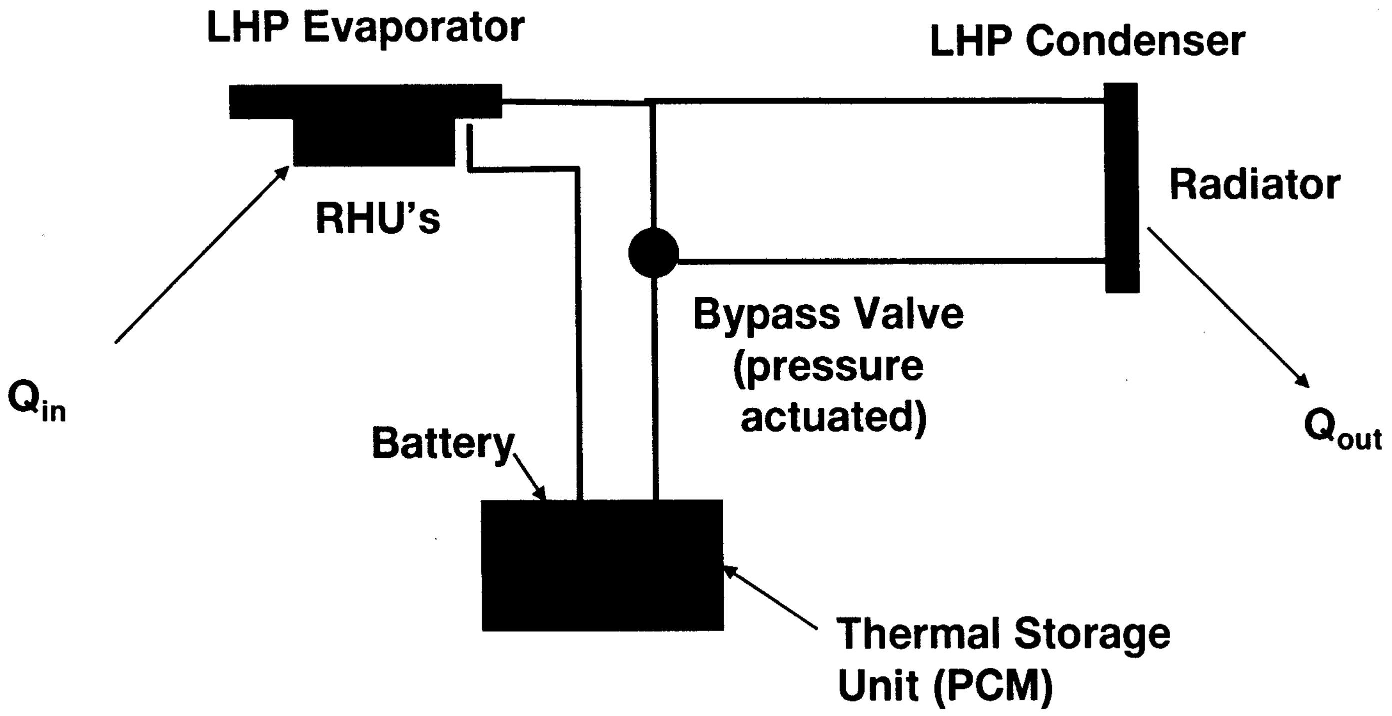
Mega-Rover for Mars Sample Return

- Mass = 750 kg (1650 lbm)
- Solar Array Area = 7.0 m^2 (75 ft^2)
- Wheel diameter = 70 cm (28 in)
- Max Power = 175 W
- Secondary Battery
- Design Life = 90 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 & Pumped Fluid Loop



Athena Mars Rover Battery Thermal Control Concept

Variable Conductance LHP with PCM Thermal Storage



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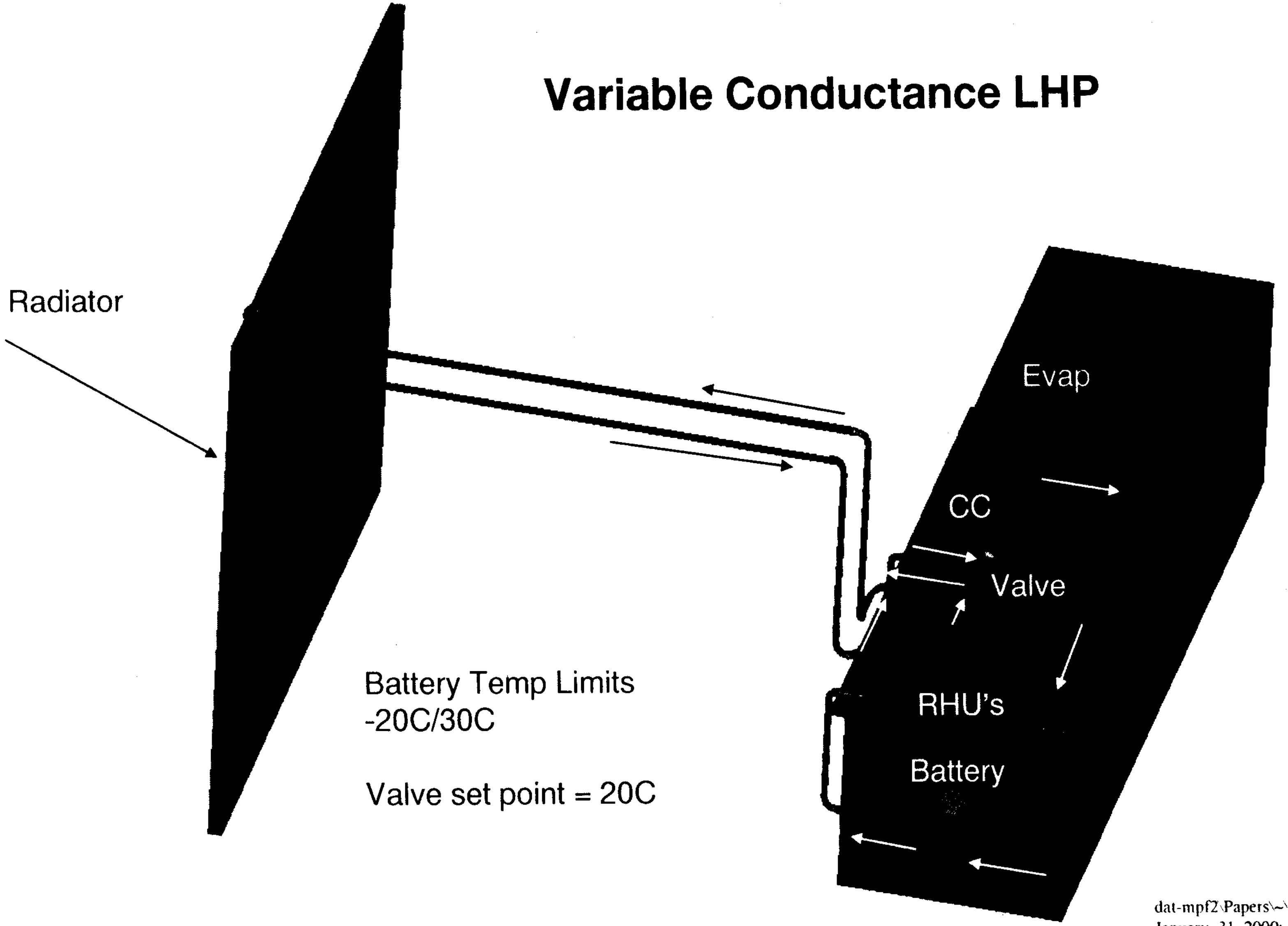
Athena Rover Battery Thermal Control

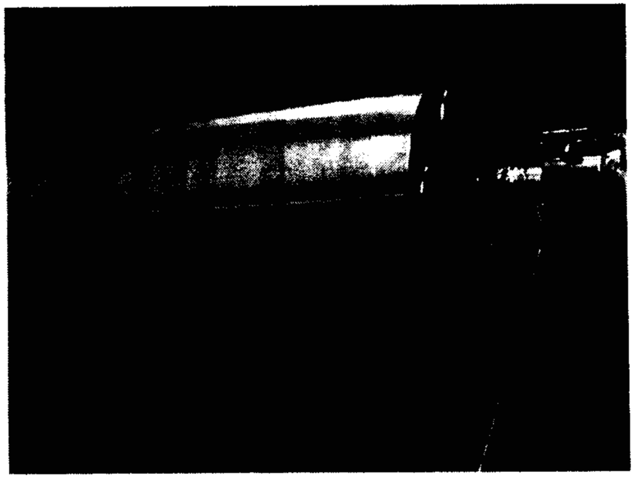
Variable Conductance LHP



Battery Temp Limits
-20C/30C

Valve set point = 20C

Phase Change Thermal Storage



Description:

- Phase change material (PCM) utilizes latent heat to protect batteries against low temp. extremes by providing thermal storage
- PCM stores excess heat when available and releases the heat when needed
- The technology is simple, reliable, and mass efficient

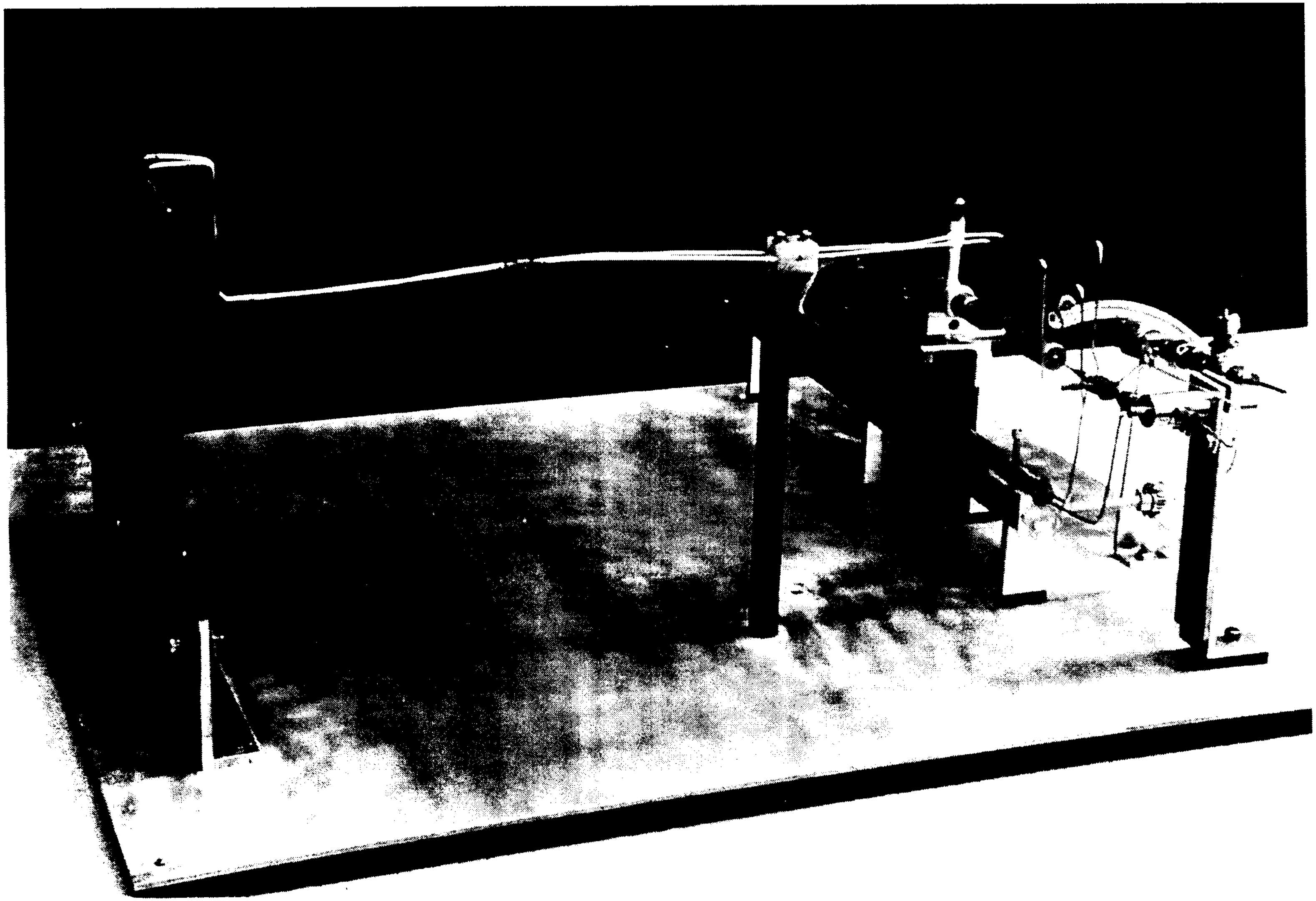
Current Status:

- Dodecane PCM material (-10 C MP) encapsulated in a carbon fiber matrix
- A battery/PCM capsule has been fabricated by ESLI for JPL
- Was tested at JPL in a simulated Martian environment to evaluate rover battery/electronics thermal control (800 g capsule provides 30 W*hr)

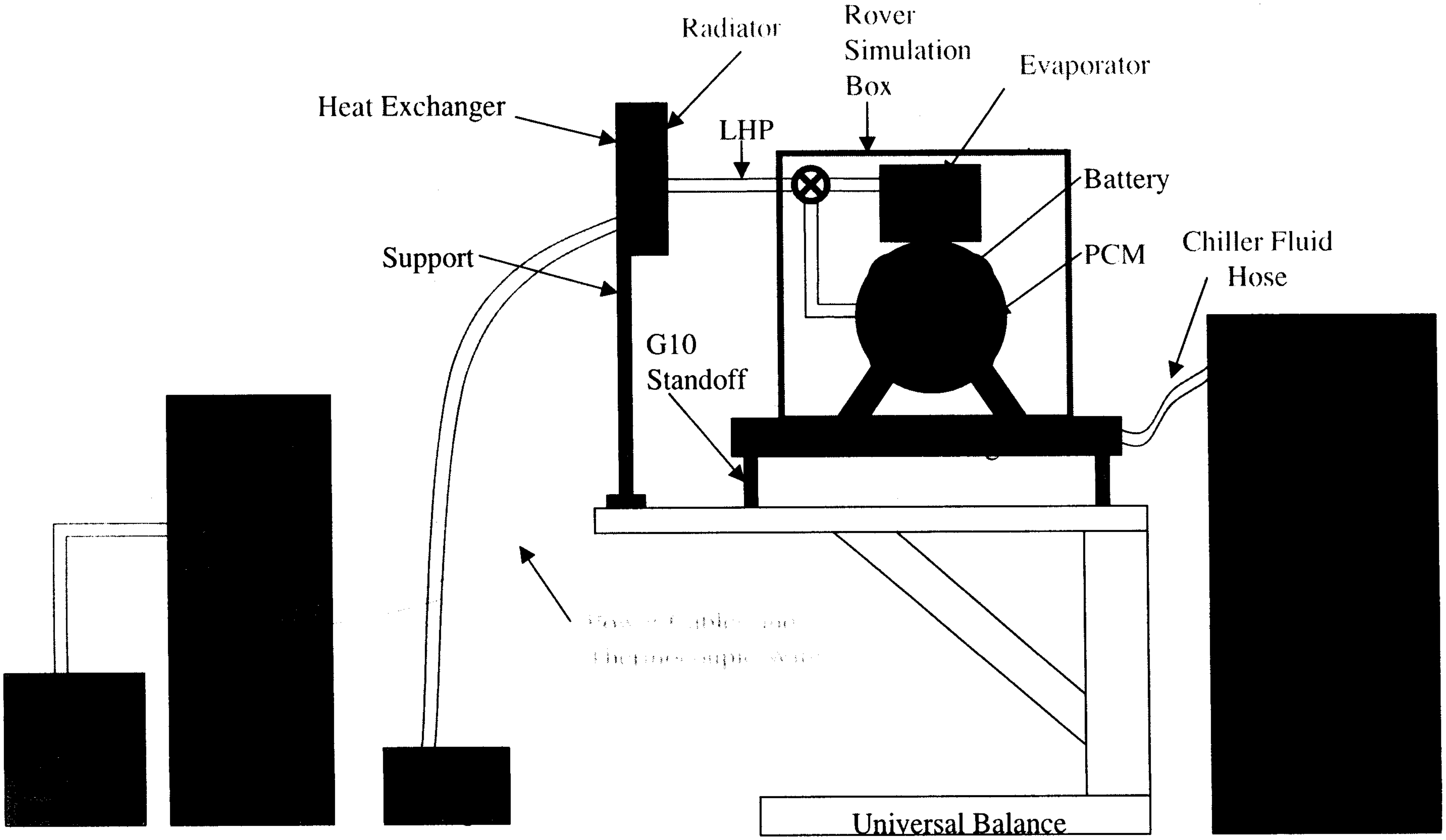
Future Development:

- Integrate PCM capsules with miniature LHP and heat switches for WEB thermal control
- Investigate PCM materials with lower MP for lower temperature operations (below -20 C)
- Design lower mass system for thermal energy management on Mars landers, in-situ experiments & Microspacecraft missions

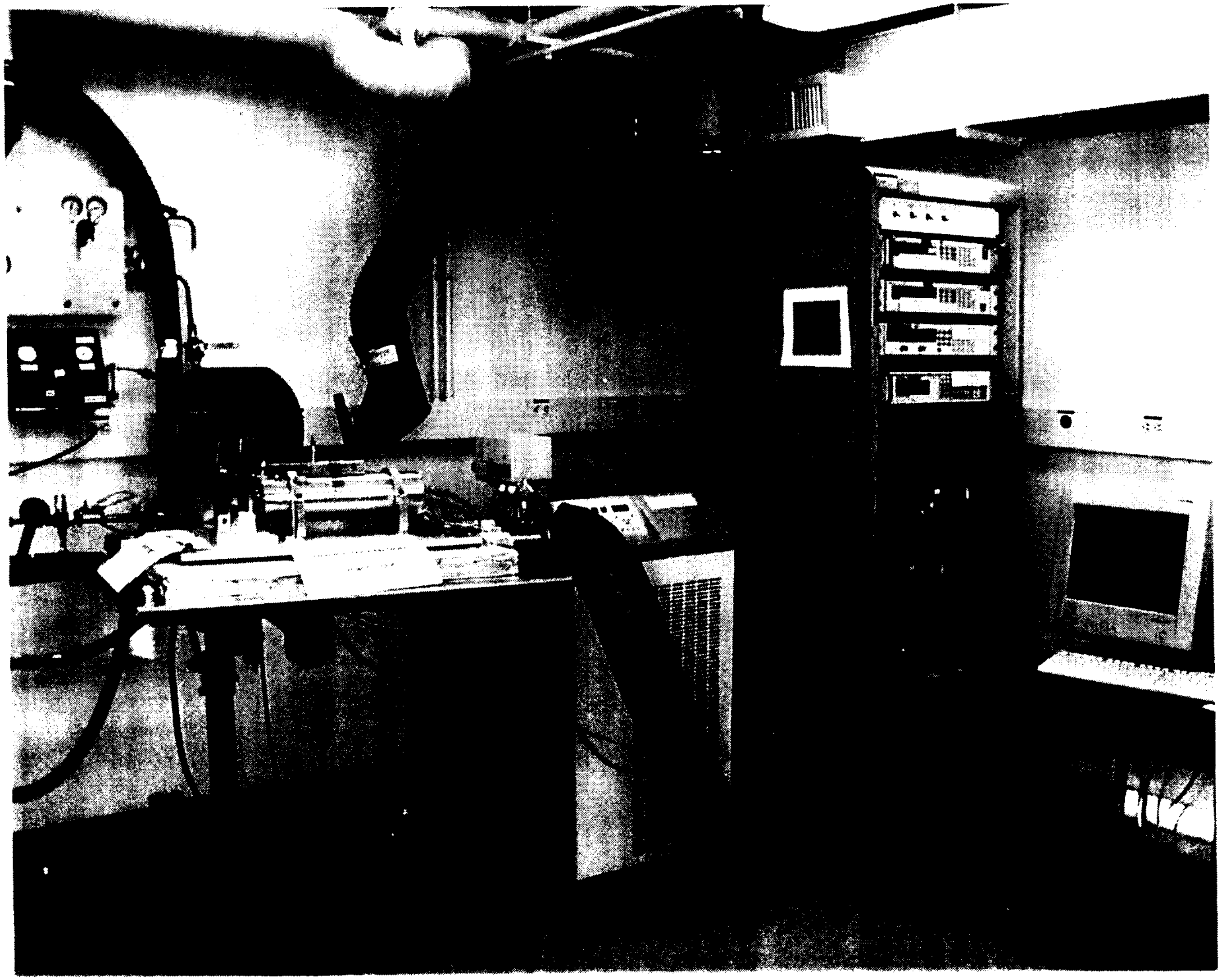
Thermal Testing - Prototype Variable Conductance Loop Heat Pipe



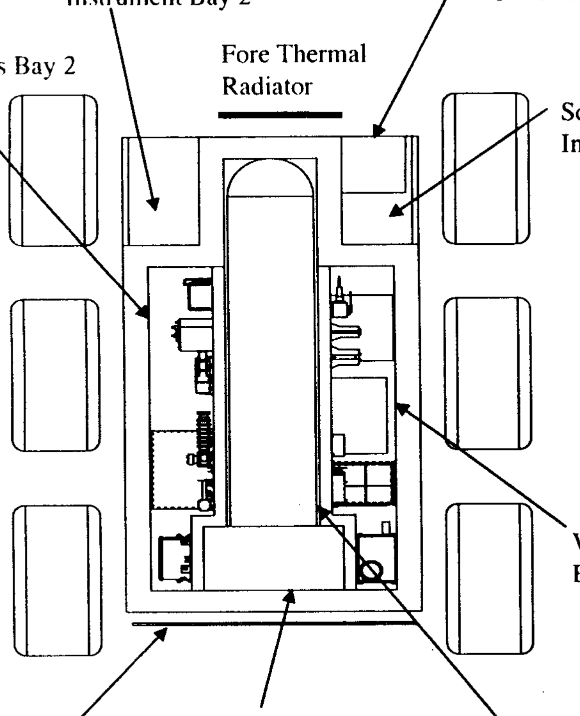
Thermal Testing - Prototype Variable Conductance LHP



JPL Miniature Loop Heat Pipe Test Bed



Mega-Rover Configuration



Science Instrument Bay 2

Warm Electronics Bay 2

Fore Thermal Radiator

Sampling System

Science Instrument Bay 1

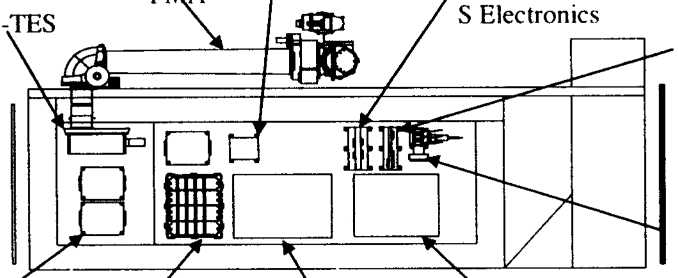
Warm Electronics Bay 1

Aft Thermal Radiator

MAV Deployment Mechanism

MAV

Top View



Mini-TES

PMA

Diode Box

Moessbauer/APXS Electronics

Raman Electronics

Raman Spectrometer

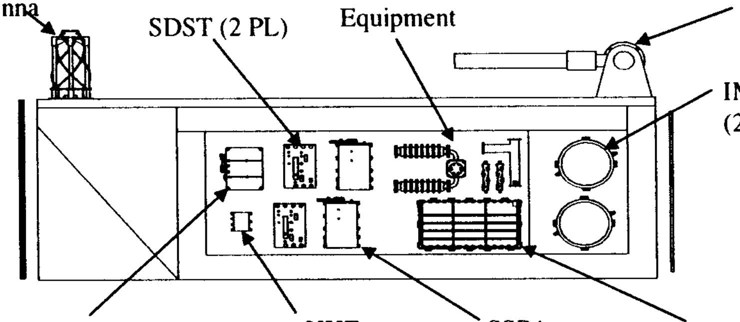
CCU (3 PL)

PDDU

Li-Ion Battery

Integrated Thermal Pump Assembly

Warm Electronics Bay 1



UHF Antenna

SDST (2 PL)

X-Band Equipment

IMU (2 PL)

UHF Tranceiver

UHF Diplexer

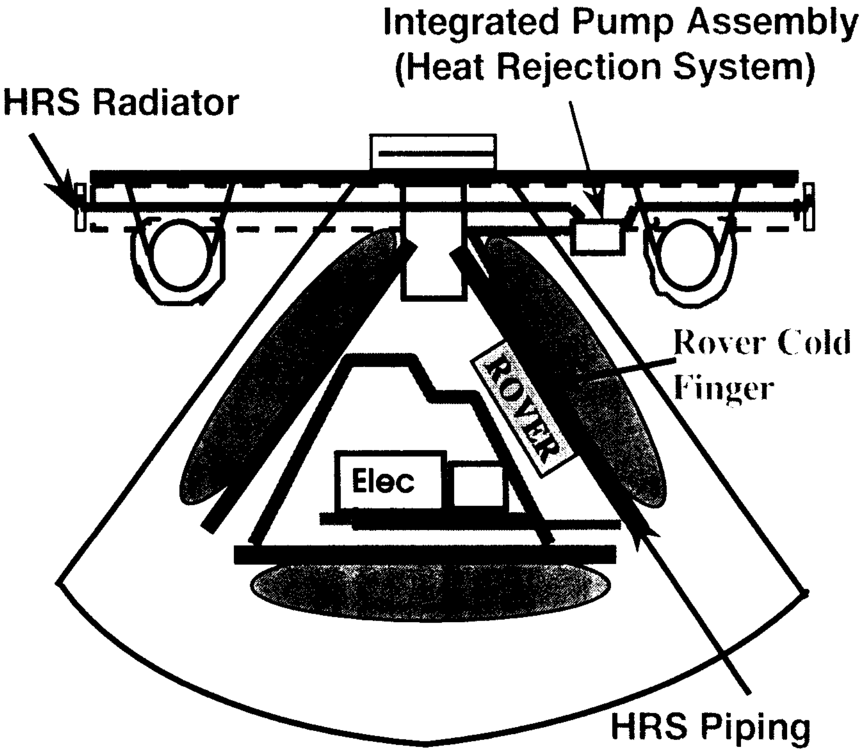
SSPA (2 PL)

CD&H Electronics

Warm Electronics Bay 2

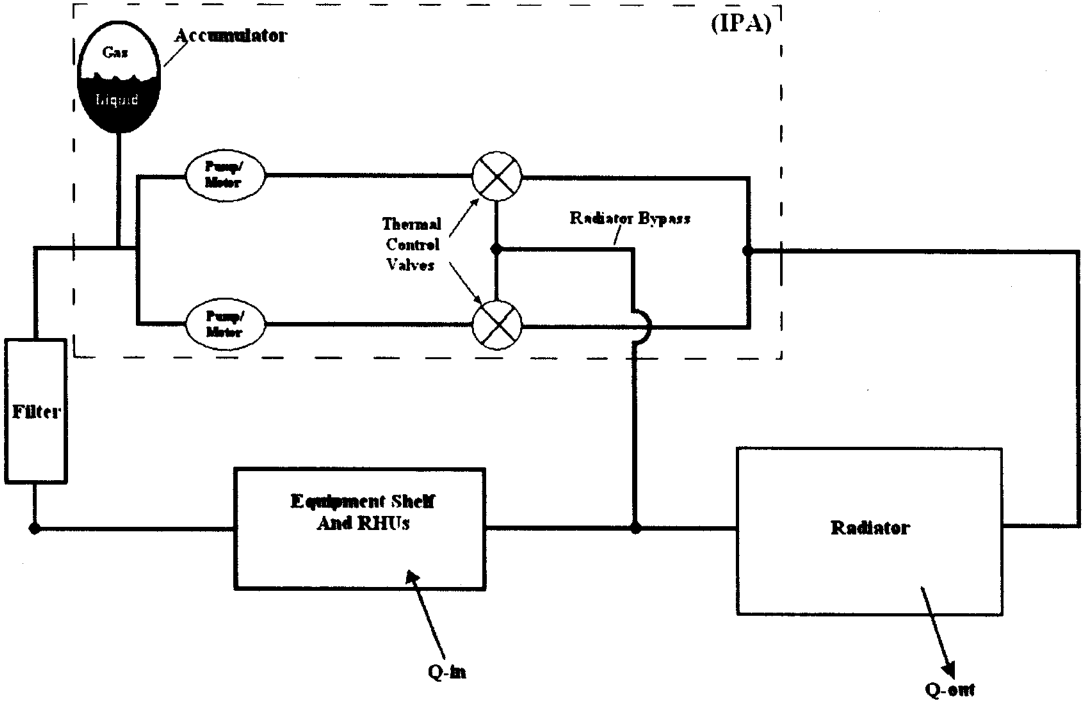
Mars Pathfinder
Mechanically Pumped Cooling Loop

- Pumped loop used during cruise to reject lander internal dissipation
- Flow rate = 0.2 GPM at 6 psid
- Capable of removing 150W over a 10C temperature difference
- Freon 11 working fluid
- Wax actuated thermal bypass valve



Mars Mega-Rover
Thermal Control Concept

Rover Heat Rejection System



- Total HRS Mass = 18kg, Power Consumption = 10W, Heat Rejection = 160W
- Integrated Pump Assembly (Mass = 8.3kg): Accumulator, 2 Centrifugal Pumps/Motors, 2 Wax Actuated Bellows Bypass Valves, Check Valves, Fill Ports, Electronics.
- Radiator, 0.040” thick Al Plate (1.3m^2), Radiator tubing 3/8” OD
- Equipment Shelf (Heat Exchanger), 0.060” thick Al Plate , Equip Shelf Tubing - 1/4” OD

Passive Cooling Loops vs Active Cooling Loops

- Passive Loops:
  - Based on two-phase heat pipes (e.g., loop heat pipe)
  - Can function in adverse gravity gradients (several meter high), can reject heat over large areas, no electronic controls needed
  - Demonstrated life of over 8 years in flight (Russian S/C)
  - Entire unit is welded and sealed, heat collection limited to the evaporator foot print, limited heat transfer capacity due to passive nature
- Active Loops:
  - Mechanical pumps circulate single-phase fluid between source and sink
  - Gravity insensitive, can use mechanical joints, can handle large powers, can easily handle additional loads
  - 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 160 W heat), electronics for motor control, accumulator

Conclusion

- Larger, more capable rovers require more sophisticated thermal control designs (passive & active loops) to handle increased thermal loads

- Whichever rover mission gets chosen by NASA Headquarters (Marie Curie, Athena, Mega-Rover) we have a thermal system that can handle the extreme thermal environments of Mars missions
  - Marie Curie has Mars Pathfinder rover (Sojourner) heritage
  - Athena rover variable conductance LHP currently undergoing testing, extensive analysis of thermal design has been done
  - Mega-Rover pumped fluid loop thermal design has MPF lander cruise environment heritage

Presenter's Introduction

- Keith Novak -
  - Keith is a Senior Engineer in the Thermal and Propulsion Engineering Section at JPL where he has been working for the last nine years. His current areas of interest are spacecraft thermal control design, thermal hardware implementation, and advanced thermal control technologies for Mars landers and rovers. Keith received a B.S. degree in Mechanical Engineering from Duke University and a M.S. degree in Mechanical Engineering from Arizona State University.