Advanced Thermal Control Technology for Space Applications

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June 23-26, 2003

Presented at
34th Annual Thermophysics Conference
American Institute of Aeronautics and Astronautics
Orlando, Florida

JPL Advanced Thermal Technology Team

Pradeep Bhandari:	Pumped Fluid Loops, Long-Life Pumps
Gaj Birur:	Pumps, Pumped Fluid Loops, LHP etc
Gani Ganapathi:	MER Heat Rejection System
Keith Novak:	Loop Heat Pipe and MER Heat Switch
Tony Paris:	MEMS based Pumped Liquid Loop
Mike Pauken:	Loop Heat Pipe and MER Heat Switch
Jose Rodriguez:	TES Loop Heat Pipes
Eric Sunada:	MER Heat Switch
Glenn Tsuyuki:	Light Weight Insulation and MER HRS

OUTLINE

- Background
- Future JPL Missions
- JPL Thermal Control Technology Roadmap
- Specific Technologies Under Development
- Conclusions

Advanced Thermal Control Technologies

- Future NASA deep space science missions will be complex and diverse in terms of thermal environments and requirements
- Current thermal control technologies are not be able to meet the science objectives of these missions
- Advanced thermal technologies and architectures are needed to meet the cost, mass, volume, and capability requirements of future missions
- JPL is developing several advanced spacecraft thermal control technologies working with other organizations

Future Space Science Missions at JPL

- **Mars Missions**
  - Mars missions - landers, rovers, in-situ production experiments, and robotic support for human colonization missions, Mars Micro Missions. MER (2003), MRO(2005), Mars Scout (2007), and Mars Science Laboratory (2009)
- **Other Deep Space Missions**
  - Missions to comets/asteroids - e.g., Comet Nucleus Sample Return, asteroid exploration & sample return
  - Missions to other Planets - Europa orbiter/lander, Venus Surface Sample Mission, Jupiter Multiprobe, Titan In-Situ Mission, Saturn Ring Observer, Neptune Orbiter
- **Other Missions -** Earth orbiting spacecraft/science payload, space telescopes, space interferometer missions, and science instruments

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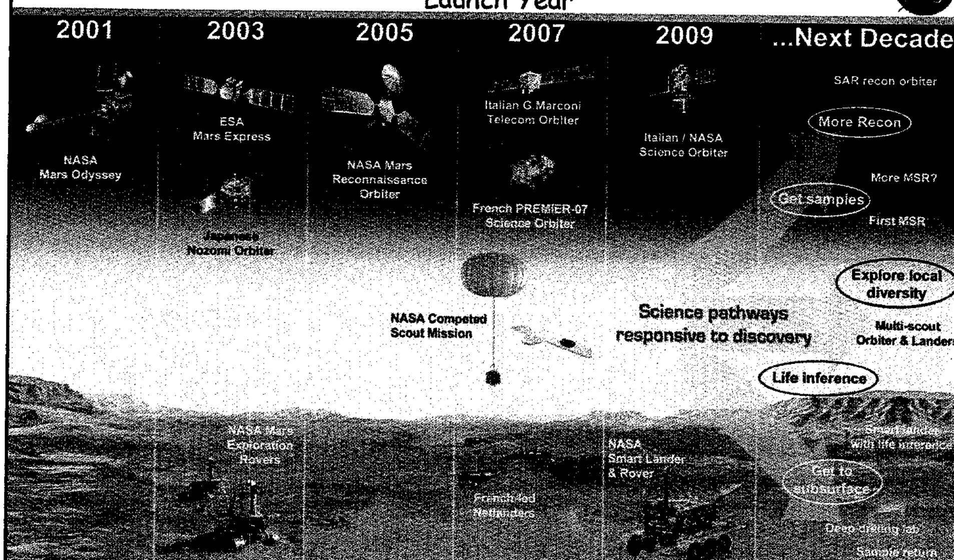
Mars Exploration Program

Launch Year



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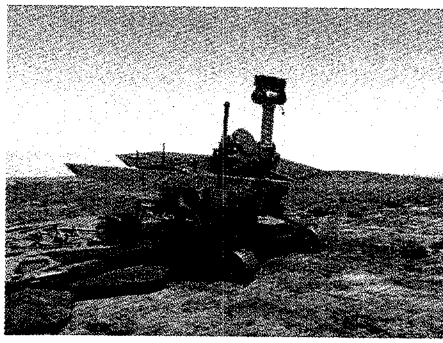
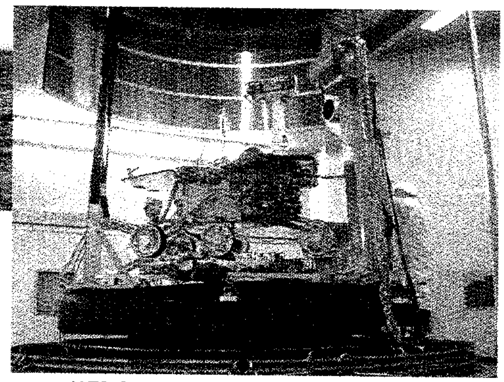
Mars Exploration Rover

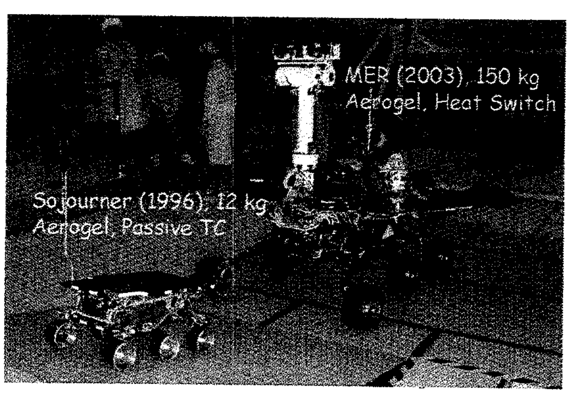


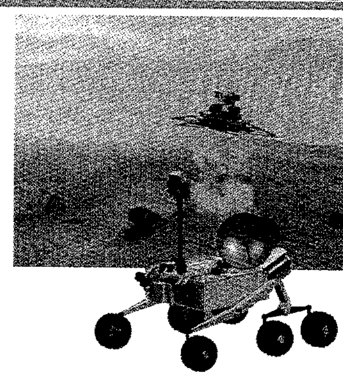
Mars Exploration Rover (2003)



MER Rover test in December 2003

Mars Rovers - Past, Present, and Future



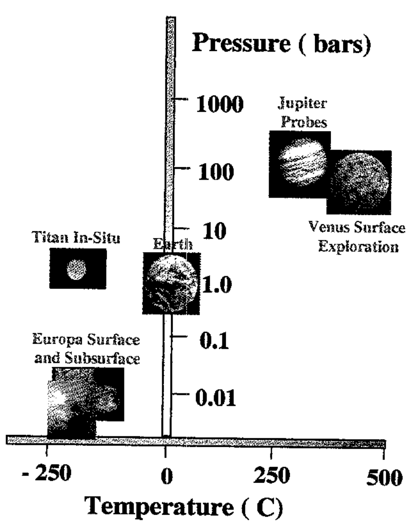


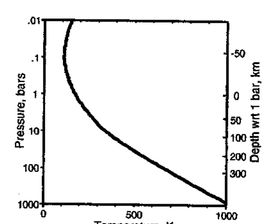
MSL (2009), ~ 750 kg
Pumped Cooling Loop
(Pre-decisional configuration)

JPL Extreme Environments in Future Space Missions

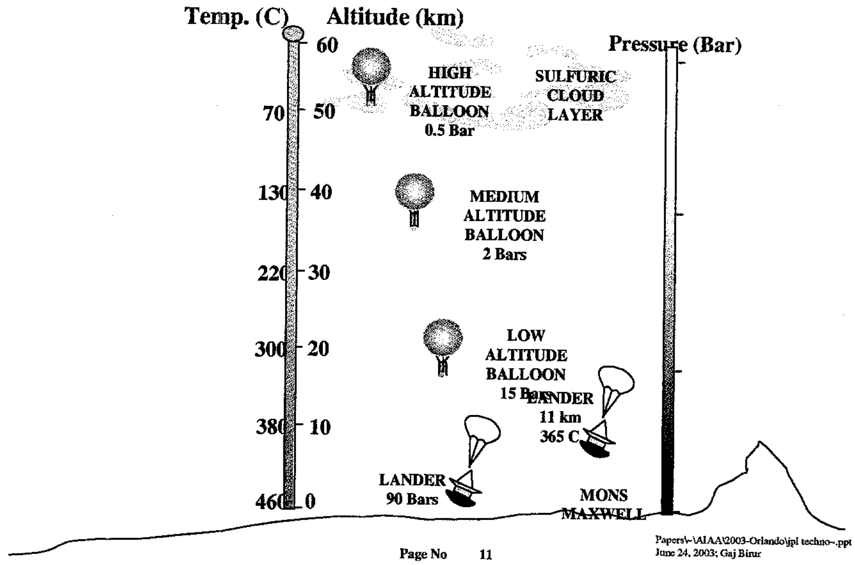
Mission	Low Temp. C	High Temp., C	High Radiation Levels	High Pressure	Other Environmental Conditions
Venus Surface Exploration and Sample Return		460		90 bar	Sulphuric acid clouds at 50 km 97% CO_2 at the surface
Giant Planets Deep Probes	-140	380		100 bar	
Comets Nucleus Sample Return	-140				Dust
Titan In-Situ	- 180			1.5 bar	2-10% Methane Clouds Solid/liquid surface
Europa Surface and Subsurface	-160		5 MRad		

JPL Planetary Extreme Environment





JPL Venusian Environment



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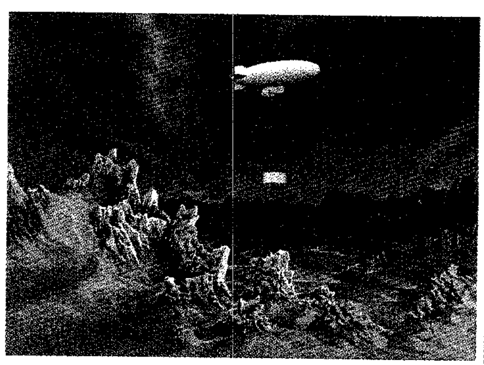
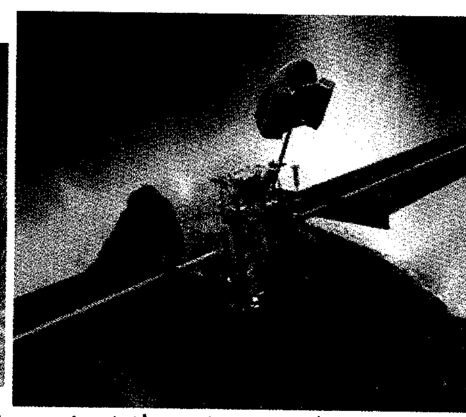
JPL Titan In-Situ and Comet Environment





Thermal technologies needed to protect the science and engineering equipment to survive and operate in Titan/Comets low temperature (- 180 to - 140 C) environment:

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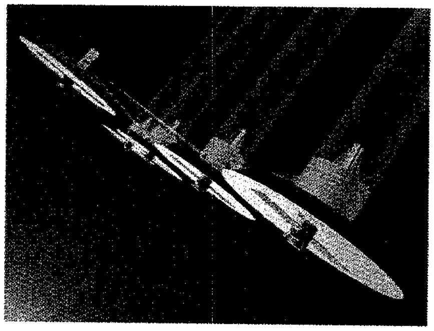
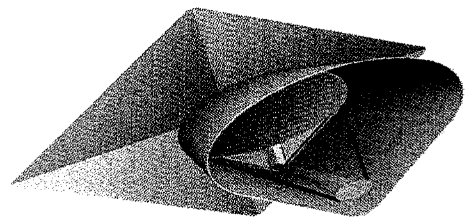
JPL Space Interferometer Missions

- Space Interferometer Missions, Terrestrial Planet Finder, and future space telescope missions need picometer accuracy and 100 micro-Kelvin temperature stability



Infrared Interferometer based on formation flying telescopes



Visible light Coronagraph Concept for Terrestrial Planet Finder

JPL JPL Thermal Control Technology Roadmap

Technology	Applications
PASSIVE TECHNOLOGIES	
Loop Heat Pipe	Mars rovers, Microspacecraft, Deep Space Missions
PCM Thermal Storage	Mars, Comets, Extreme Env. Missions
Heat Switches	Deep Space, Mars rovers, Earth Orbiting Missions
Variable Emitt. Devices	Deep Space, Earth Orbiting, Microspacecraft Missions
Passive Loop Arch.	Mars, Deep Space, Earth Orbiting Missions
ACTIVE TEHNOLOGIES	
Long life pumps	Deep Space, Earth Orbiting, Mars Rovers, Comm. Sats.
High-temp.loops	Deep Space, Mars Rover Missions
Active Micro-cooling Sys	Microspacecraft, Earth Orbiting, Deep Space Missions
Active Loop Architecture	Mechanically Pumped Cooling Loop Based Architecture

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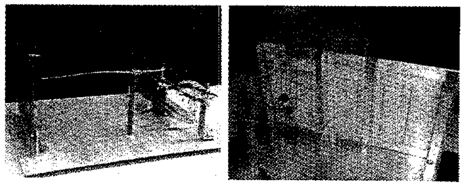
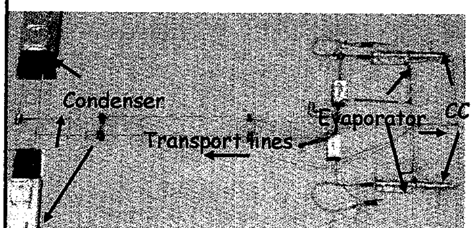
JPL

Loop Heat Pipe Technology
(Small Size/Capacity LHPs)



Miniature LHP for Mars Thermal Control



Dual Evaporator Miniature LHP

Description:
- A versatile thermal control device: transfers heat, controls temps., and act as a heat switch (all in one)
- Light weight (< 200 gms to transfer 60 W) device compared to other the hardware of same function
- Enormous flexibility in locating heat sources and sinks on the spacecraft

Participants & Facilities:
- JPL is investigating this technology for Mars rover & μS/C applications
- Tests performed at JPL and Goddard during FY00-02 for evaluating miniature multiple evaporator LHP
- Dynatherm Corp (Swales) designed and fabricated a miniature LHP

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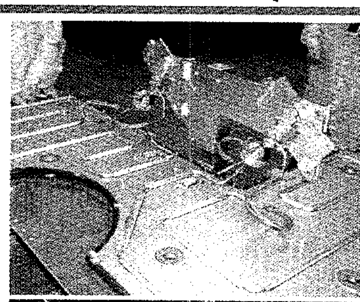
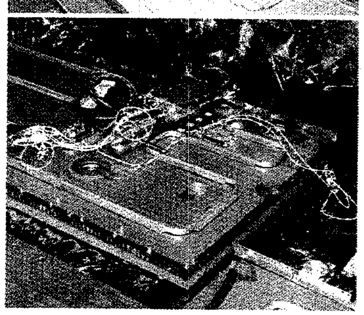
EOS-TES Loop Heat Pipes
(Full Size/Capacity LHPs)





- **EOS-TES is using five LHPs in its thermal design (Jose Rodriguez)**
- **Propylene LHPs in the 75 to 150 W range**
- **Instrument level tests successfully completed in early 2003**
- **TES to be integrated on EOS spacecraft for system level tests**

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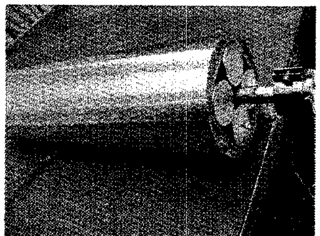
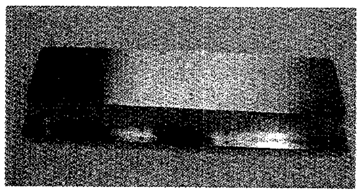
JPL — Phase Change Material (PCM) Thermal Storage Technology



Dodecane PCM Thermal Storage Unit
(Melting point, -10.5 C)



Hexadecane PCM Thermal Storage
(Melting Point temperature 18 C)

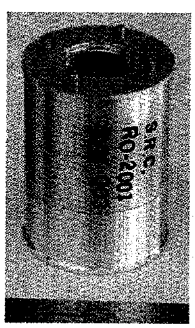
Description

- Phase change material (PCM) utilizes latent heat to protect equipment against temperature extremes by increasing thermal capacity
- PCM stores excess heat when available and releases when needed
- The technology is simple, reliable, and mass efficient

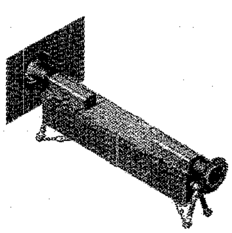
Current Status

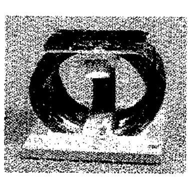
- A dodecane (MP -10.5 C) PCM capsule (ESLI, San Diego) was integrated with miniature LHP and tested for Mars rover battery thermal control
- A Hexadecane (MP, 18 C) PCM from ESLI is being evaluated for Mars rover battery thermal control at JPL

JPL — Heat Switch for Space & Mars Surface Applications



MER
Wax Actuated
Heat Switch
(Starsys,
Boulder, CO)





Lightweight
Heat Switch
(ESLI,
San Diego, CA)

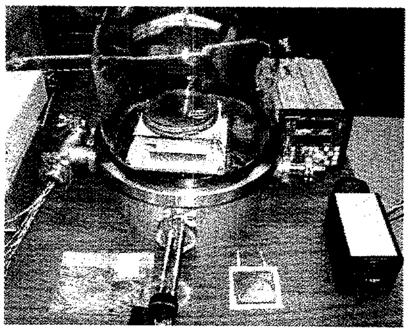
Description

- Wax actuated heat switch for Mars with target performance of 0.4 W/C, switch ratio of 30 in 8 torr CO_2, weighing less than 120 gms
- A miniature lightweight high performance heat switch using phase change material actuator (FY02 - 0.34 W/C, 8.5 gms, close/open ratio of 40 in vacuum)

Participants & Facilities

- Wax actuated heat switch for MER was developed by Starsys. in Boulder, CO
- Miniature heat switch development is conducted by ESLI, San Diego, CA under NASA SBIR II

Variable Emittance Devices (Electrochromic)



Electrochromic Device Testing at JPL

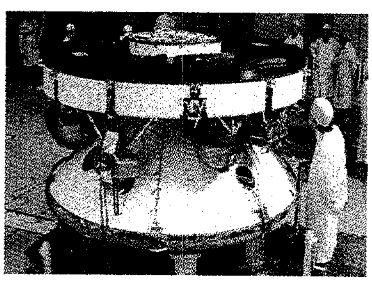
Description

- A change of surface emissivity in the range of 0.2 to 0.8 by an external electric field of ~ 1V dc
- Provides a low mass device(400 gm/sq m) to vary heat rejection capacity on the spacecraft

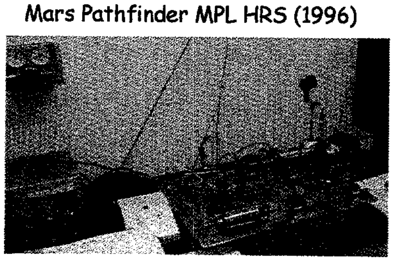
Participants & Facilities

- JPL is investigating this technology along with GSFC and AFRL for Spacecraft applications
- Conducting polymer based devices made by Ashwin-Usha
- Space endurance testing underway for UV, radiation, thermal vacuum, & micrometeroid environment at JPL and NASA GSFC

Mechanically Pumped Cooling Loops



Mars Pathfinder MPL HRS (1996)



MER HRS Pump Life Test (2002)

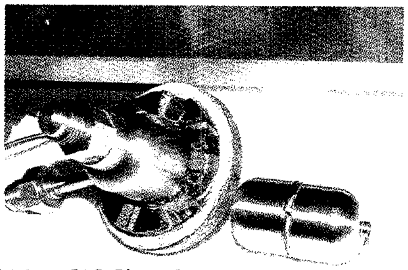
Description

- Mechanically pumped single-phase cooling loop used on Mars Pathfinder (1996) and MER (2003) for thermal control
- A pump assembly of 7 kg uses CFC-11 to remove ~160 W from spacecraft electronics to an external radiator

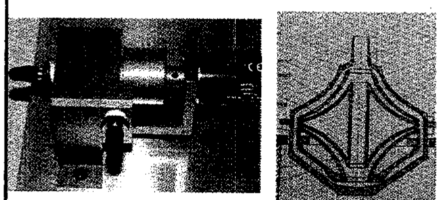
Participants & Facilities

- JPL is investigating this technology for future Mars and deep space missions
- Pacific Design Technology, Goleta, CA built the pump assembly for MER Mission
- An engineering pump unit is under life test at JPL for the last eight months

JPL Long-Life Mechanical Pumps



NASA SBIR Ph II Prototype Pump (2002)



NASA SBIR Ph I Prototype Pump (2000)

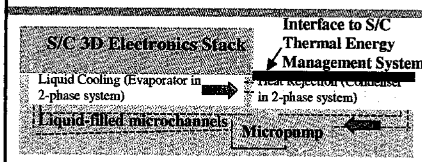
Description

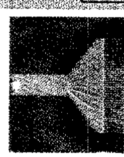
- The bearing and seal-free pump uses a floating rotor and with no seals; promises high reliability for long-term operation
- Light weight device compared to state of the art mechanical pumps (Mars Pathfinder pump) has large clearances

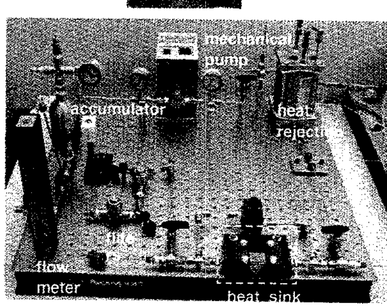
Participants & Facilities

- JPL is investigating this technology for mechanically pumped cooling loops for space applications (Mars rover, µS/C)
- Long-life testing completed (5000 hours) on Phase I pump at JPL in 2002
- Advanced Bionics Inc., in Minnesota is developing this pump for heart bypass and heart replacement functions

JPL Active Micro-Cooling Systems







Description

- MEMS based liquid pumped cooling system for high density electronics and sensors for future micro/nano Sciencecraft
- Single-phase liquid is circulated in microchannels with a mechanical pump

Participants & Facilities

- JPL is investigating this technology for high power density heat removal in microspacecraft and large spacecraft
- Other participants Stanford University and SAIC, an Diego, CA
- A microcooling test bed used for the evaluation of microchannels and micropumps

JPL

Conclusions

NASA

- The thermal control challenges posed by future NASA science missions can only be met by advanced thermal control technologies
- Both passive and active thermal control technologies are needed to enable/enhance future missions
- Both near/far term missions and large/micro spacecraft require advanced thermal technologies
- JPL is actively working with several organizations in the development of these technologies