Advanced Thermal Control Architecture for Future Spacecraft
(and JPL Technology Roadmap-2001)

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• Traditional Thermal Control Architecture for Spacecraft
• Advanced Thermal Control Architectures for Future
• Future JPL Missions
• JPL Thermal Control Technology Roadmap
• Conclusions
Traditional Spacecraft Thermal Architecture

Spacecraft Thermal requirements:

- Maintain Allowable Temperatures
- Minimize the survival heater power
- Minimize the thermal control system mass and heater power

Spacecraft Thermal Control Functions:

- Remove heat - Radiators, High Cond materials, heat pipes
- Add heat - Electric heaters, RHUs, Batteries
- Minimize survival heat - MLI insulation, louvers, thermal switch, heat pipe
Traditional Thermal Architecture - Examples

- Integrated Pump Assembly (Heat Rejection System)
- HRS Radiator
- Rover Cold Finger
- HRS Piping

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Traditional Thermal Architecture - Limitations

• Thermal design character:
  - Based on removing/adding heat to maintain temperature and minimizing survival power
  - Specific to each mission, thermal environment, and spacecraft operation scenarios
  - Full scale design, analysis, and testing needed for each mission
  - Requires significant schedule, cost, and workforce for design, analysis, and test

• Drawbacks of this architecture include:
  - Longer design, build, and launch cycles
  - Larger survival heating power requirement
  - Additional heater power for better temperature control of equipment and instruments
  - May not be robust for late spacecraft design changes
Traditional Thermal Architecture - Limitations

• Thermal design character:
  - Based on integrated thermal energy management (ITEMS), excess heat from a spacecraft location utilized at locations where it is needed
  - Not mission-specific; same architecture for landers, orbiters, flybys with diverse thermal environment,
  - Full scale design, analysis, and testing not always needed for each mission

• Benefits of this architecture include:
  - Shorter design, build, and launch cycles
  - Low survival heating power requirement (Mars diurnal application)
  - Better temperature control of equipment and instruments
  - Robust for late changes in spacecraft design
  - Same design used for several missions
Traditional Thermal Architecture - Heat Balance

Solar Array Power, \(\sim 300 \text{ W}\)

HRS Radiator

Electronic Heat Rejection, \(\sim 160 \text{ W}\)

Propulsion Heater, \(\sim 40 \text{ W}\)

Other Heaters, \(\sim 40 \text{ W}\)

HRS Piping
Integrated Thermal Energy Management (ITEM) Systems for Future Spacecraft
Future Advanced Thermal Technology Needs

Electrochromics Coatings

LHP Evaporators

BATTERY

T/S

SCIENCE/OTHER

PROPULSION

LHP loop

Spacecraft Envelope

Electrochromics Variable Emissivity Radiator
Future Space Science Missions at JPL

- Mars missions - landers, rovers, in-situ production experiments, and robotic support for human colonization missions, Mars Micro Missions. MER (2003), Mars ‘05 Orbiter (2005), Mars ‘07 Mega Lander (2007)

- Missions to comets/asteroids - e.g., Comet Nucleus Sample Return Mission, asteroid exploration and sample return

- Missions to other Planets - Europa orbiter/lander, Pluto/Kuiper Express (2008), Saturn Ring Observer, Neptune orbiter

- Other Missions - Earth orbiting spacecraft/science payload, space telescopes, instruments

- Microspacecraft Missions
JPL Thermal Control Technology Roadmap

Battery Thermal Control
Mars Rover

Lightweight Thermal Insulation
Mars Applications

Variable Emittance Devices

Miniature Heat Switch
(NASA SBIR Ph. II, ESLI)

Bearing and Seal Free Pump
(NASA SBIR Ph. II, ABI)

MEMS based Liquid Cooling

Passive Cooling Loop Based
Thermal Architecture

Active Cooling Loop Based
Thermal Architecture

Mini Loop Heat Pipe/PCM Thermal Storage

Electrochromic Radiators

Miniature Heat Switch

Loop Heat Pipe Thermal Energy Management

Mechanically Pumped Cooling Loop Based Thermal Architecture
Phase Change Thermal Storage Technology

Current Status:
- Dodecane PCM material (-10 C MP) encapsulated in a carbon fiber matrix
- A battery/PCM capsule was fabricated by ESLI for JPL
- It is integrated with miniature LHP and being tested at JPL in a simulated Martian environment to evaluate rover battery/electronics thermal control

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

Future Development:
- Investigate PCM materials with lower MP for lower temperature operations (below -20 C)
- Develop and qualify low mass system for thermal energy management on Mars landers, in-situ experiments and Microspacecraft missions
Participants & Facilities
- JPL is investigating this technology for space applications (Mars rover/lander, micro S/C)
- Tests to be performed at JPL and Goddard during FY00 for evaluating miniature multiple evaporator loop heat pipe
- Dynatherm Corporation has designed and fabricated a miniature loop heat pipe for Mars Rover battery thermal control concept

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 for DSST 2nd Delivery
- This technology is applicable to small & large S/C and planetary vehicles thermal control
Variable Emissivity Surfaces (Electrochromic)

Description

- A change of surface emissivity in the range of 0.3 to 0.8 by an external electric field of < 5V
- Provides a low mass device (400 g/m²m) to vary heat rejection capacity on the spacecraft
- Conducting polymer material used as electrochromic material
- Devices based on similar materials used for automotive and building energy conservation

Status & Future Applications

- Significant work by EIT labs, LBL Berkeley, ASHWIN-USHAS, NASA Lewis
- JPL, GSFC & AFRL investigating for S/C use
- Excellent candidate for JPL's Integrated Thermal Energy Management (ITEM) systems for future spacecraft
- Initial validations tests at 10 Mrad Gamma radiation
- Space qualification of the material as an important next step:
  - Thermal vac and radiation tests at JPL
  - Solar wind tests at GSFC
- Device failure mechanisms in space applications need to be understood
Light Weight Thermal Insulation for Martian Surface

Description:
- High performance light weight insulation being developed for Mars surface conditions
- Multi-layer insulation (MLI) based designs developed to replace Batt insulation
- Second generation aerogel based insulation in rigidized configuration is being developed

Current Status:
- MLI based insulation is used on Mars ’01 lander electronic box
- A rigidized aerogel insulation configuration are being fabricated at JPL and ESLI
- Thermal tests on rigidized aerogel samples will be tested during last quarter of 1999

Future Development:
- Investigate the use of rigidized aerogel for Mars Rover applications
- Investigate inflatable insulation for spacecraft for both vacuum and Martian environment
Lightweight Rigidized Aerogel Insulation

Technical Description
- A lightweight high performance thermal insulation applicable to Mars surface vehicles.
- Light weight device compared to other thermal control hardware performing the same function.
- Enormous flexibility in locating heat sources and sinks on the spacecraft.

Participants & Facilities
- JPL is investigating this technology for space applications (Mars rover/lander, micro S/C
- Tests to be performed at ESLI and JPL during FY00 for evaluating performance of rigidized aerogel
- ESLI, San Diego has fabricated a version of rigidized insulation for Mars Rover and lander thermal control concept

Mission Impact & Future Applications
- This technology reduces Mars S/C thermal control insulation mass by over 30%.
- This is a key technology for the survival of rovers and landers on Martian surface.
- This technology is applicable to thermal control of small & large planetary vehicles.
Bearing and Seal-Free Mechanical Pump for Spacecraft Thermal Control

**Technical Description**
- The bearing and seal-free pump uses a floating rotor driven through a magnetic coupling has promises high reliability for long-term operation.
- Light weight device compared to state-of-the-art mechanical pumps (Mars Pathfinder pump).
- Various working fluids can be used in this pump.

**Participants & Facilities**
- JPL is investigating this technology for mechanically pumped cooling loops for space applications (Mars rover/lander, micro S/C).
- Tests at JPL during FY00 for evaluating long-life performance of this pump.
- Advanced Bionics Inc., in Minnesota is developing this pump for heart bypass and heart replacement functions.

**Mission Impact & Future Applications**
- This technology is a key part of the cooling loop which reduces S/C system level mass (over 4%) and allows locating heat sources and sinks on S/C and lowers overall I&T cost over 3%.
- This is a key technology for the survival of rovers and landers on Martian surface.
- This technology is applicable to thermal control of small & large planetary vehicles.
MEMS Pumped Liquid Cooling System for Micro-Nano Sciencecraft

Products

- S/C 3D Electronics Stack
- Liquid Cooling (Evaporator in 2-phase system)
- Liquid-filled microchannels
- Micropump
- Interface to S/C Thermal Energy Management System
- Heat Rejection (Condenser in 2-phase system)

Overview

- To develop MEMS based liquid pumped cooling system for high density electronics and sensors for future micro/nano Sciencecraft
- FY00: Fabrication of microchannel for test; TRL 2/3
- FY01: Selection & evaluation of micropump; TRL 2/3
- FY02: Design, fabrication, and testing of complete cooling system; TRL 3

Participants:

- Jet Propulsion Lab - Gaj Birur (PI)
- Goddard Space Flight Center - Ted Swanson
- Stanford University - Prof. Tom Kenny
- SAIC, San Diego - Dr. Tricia Sur
- Micro Device Labs (MDL) at JPL & Stanford and Thermal Flight Systems & Technology Lab at JPL

Customers:

- Primary Enterprise Customer: Code S, Solar System Exploration missions to Mars & other planets, SEC missions (GSFC)
- Secondary Enterprise Customer: Code Y, advanced sensors, high power density payload
Micro/Nano Spacecraft - Microcooling Task

Microcooling test setup in JPL B18-101

Test fixture with microchannel device

Microchannel in the test setup

LabView Data acquisition Software
Conclusions

- Advanced thermal architecture is an important part of JPL’s future space science missions

- The advanced technologies being investigated include both enabling and enhancing the technologies

- These technologies span both near/far term missions and large/micro spacecraft

- Technology development at JPL is conducted with collaboration with other organizations