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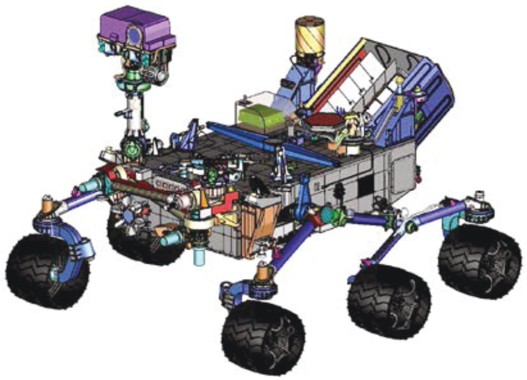

Design and Preliminary Performance of the Mars Science Laboratory Rover Heat Exchangers

A. J. Mastropietro, John Beatty, Frank Kelly, Gajanana Birur, Pradeep Bhandari, Michael Pauken, Peter Illsley, Yuanming Liu, David Bame, and Jennifer Miller

Jet Propulsion Laboratory, California Institute of Technology

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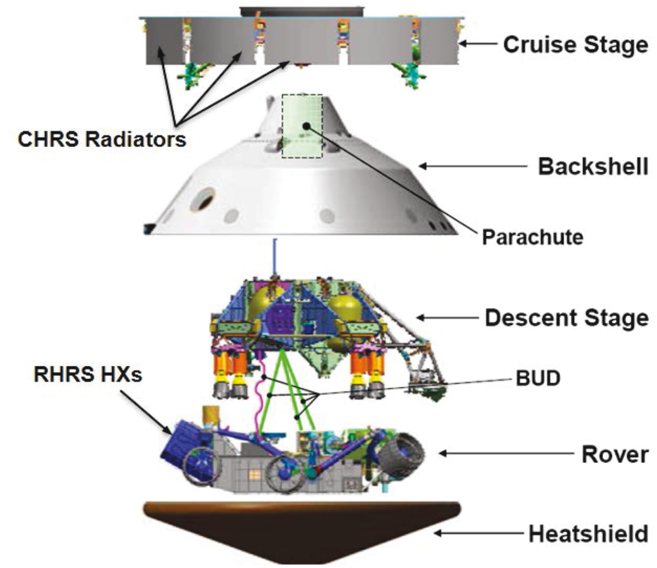
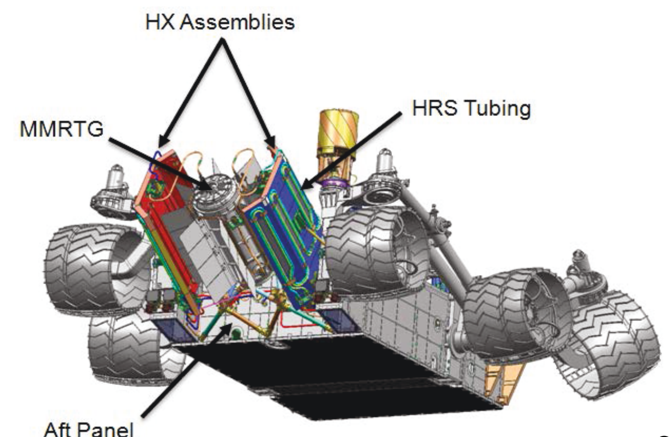
Agenda

- MSL Mission and Thermal Management Architecture
- Dual Role of Rover Heat Exchangers
- Rover Loop Surface Operation Description
- Historical Evolution of the Rover Heat Exchangers (HXs)
- Design and Fabrication of the Rover Heat Exchangers (HXs)
  - Mechanical and Thermal Design of the HX Sandwich Panels
  - Mechanical and Thermal Design of the Heat Rejection System (HRS) Tubing
- Thermal Model of the Rover HX Assemblies
- Comparison of Thermal Model Predictions to Cruise Phase System Thermal Vacuum Test Data
- Conclusions

MSL Mission and Thermal Management Architecture

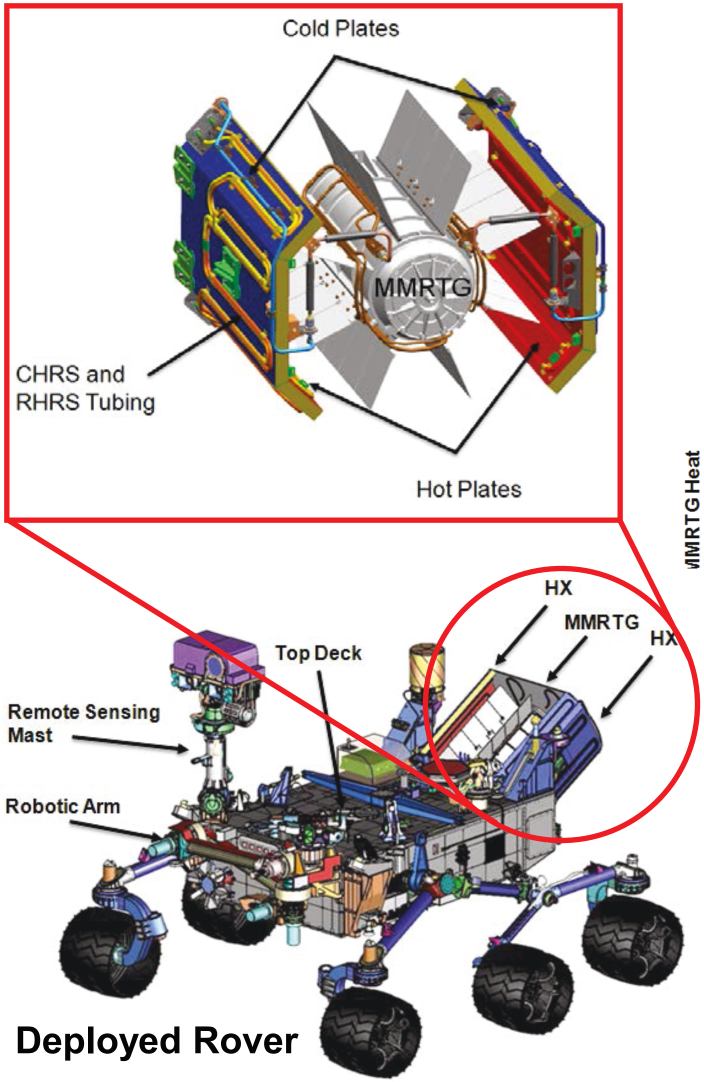
- Launch Oct 2011, payload of 10 instruments
- Landed Phase Mission Duration: 1 Martian Year
- Required to fully operate on Mars between 30^{o} North and 30^{o} South latitudes *day or night*
- New power source required – Multi-Mission Radioisotope Thermoelectric Generator (MMRTG): 110 W electrical, 2000 W thermal dissipation
- Martian surface temperatures range from -123^{o}C to 38^{o}C while Rover Electronics and Instruments need to be maintained at -40^{o}C to 50^{o}C
- Thermal Management provided by 2 Mechanically Pumped Fluid Loops (Freon): Cruise Loop & Rover Loop





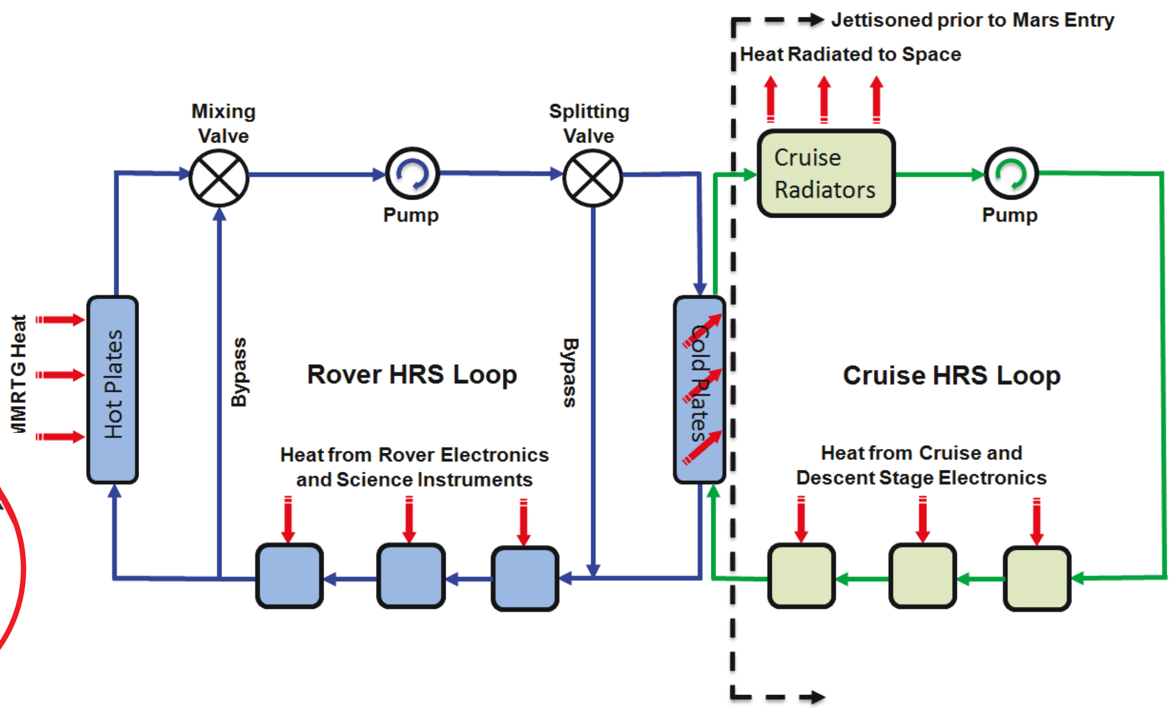
Stowed Rover

Dual Role of Rover Heat Exchangers (HXs)



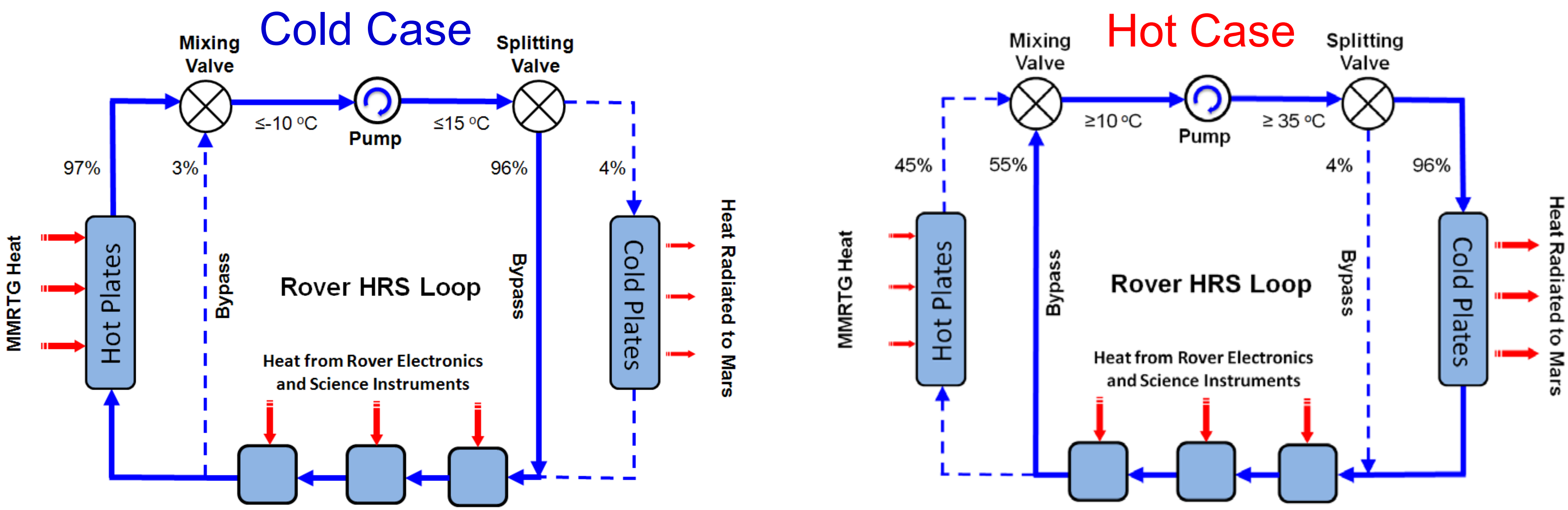
Deployed Rover

MSL Mechanical Pumped Fluid Loop Architecture



Simultaneously collect heat from MMRTG ***and*** reject waste heat to either the Cruise Loop or directly to Martian environment depending upon mission phase

Rover Loop Surface Operation Description



- HX design must allow for enough heat transfer between Hot Plate to Cold Plate to prevent the Cold Plate fluid from freezing – optimum through panel thickness thermal conductivity
- In the hot case, sufficient fluid must circulate through the Hot Plates to prevent the MMRTG and Freon from overheating

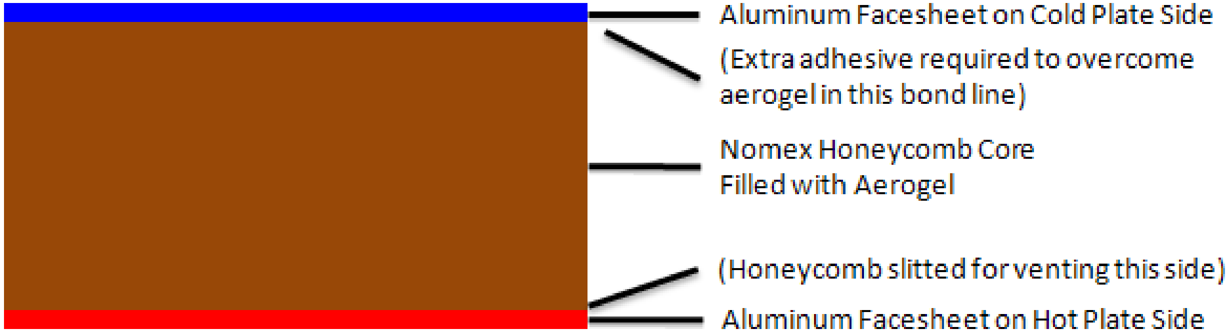
Historical Evolution of the Rover HXs

- Early trade studies:
  - Locating the radiators on the Rover Top Deck, side panels, bottom belly pan, or next to the Hot Plates
  - The number (1 or 2), orientation (horizontal, vertical, or angled) of the Hot Plates
  - Method of coupling the Cold Plate to the Hot Plate (thermal switches versus fixed conductance)
- General requirements to consider:
  - Available unobstructed surface area at a premium within a tight Rover envelope
  - Provide a platform for easy routing of the Rover Loop tubes back and forth between the HXs and the Rover chassis
  - Incorporate the required thermal isolation between the Hot Plate and Cold Plate

Design and Fabrication of the Rover Heat Exchangers

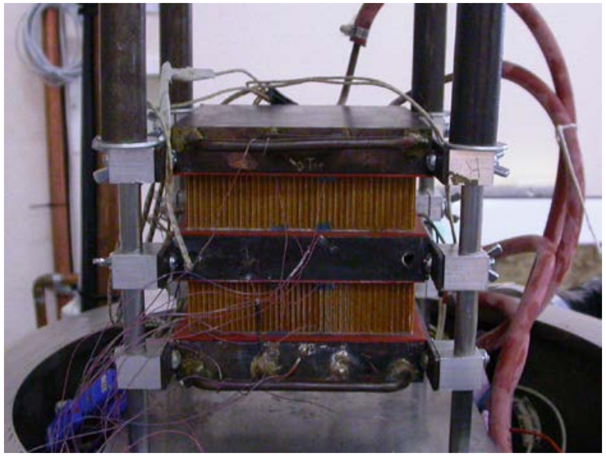
- Relevant Thermal Requirements:
  - through panel thickness thermal conductivity to be between 0.35 W/°C to 0.55 W/°C
  - In-plane thermal conductivity greater than 0.1W/°C
  - Hardware temperature limits between -111°C to 90°C
  - Maximum gradient of 60°C between Hot and Cold plate side

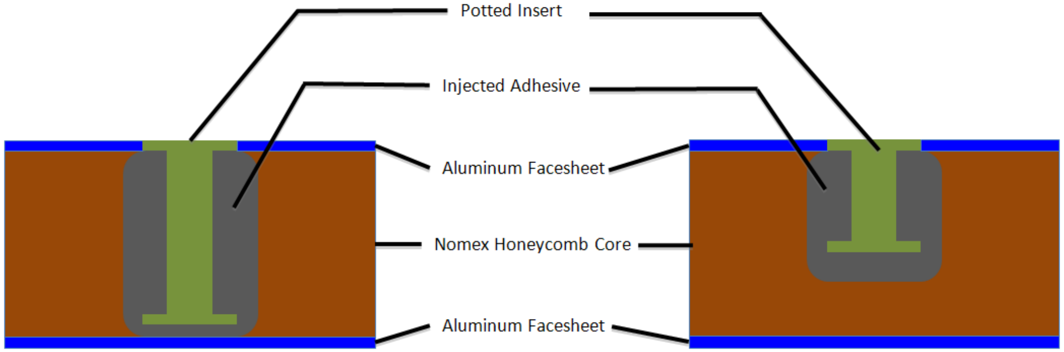
Cross Section of Rover Heat Exchanger Sandwich Panel



Thermal and Mechanical Design of Sandwich Panels

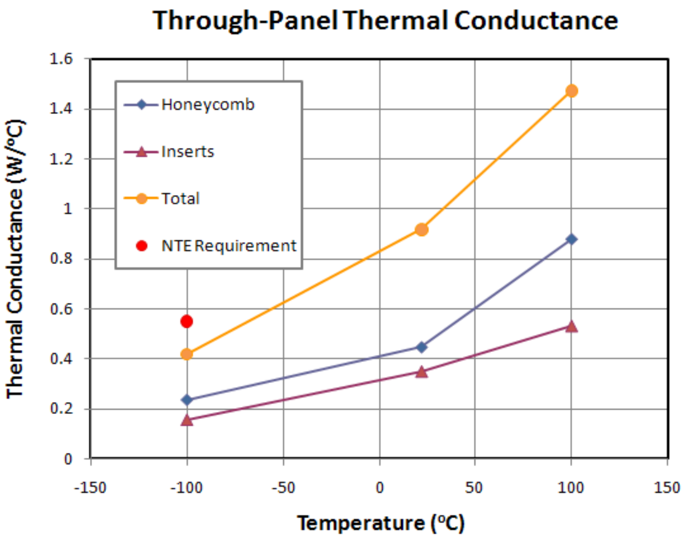
- Customized potted insert design
- Opaque Aerogel in powder form implemented as radiation suppressant
- Through panel conductivity tested using ASTM C-177 Guarded Hot Plate Test



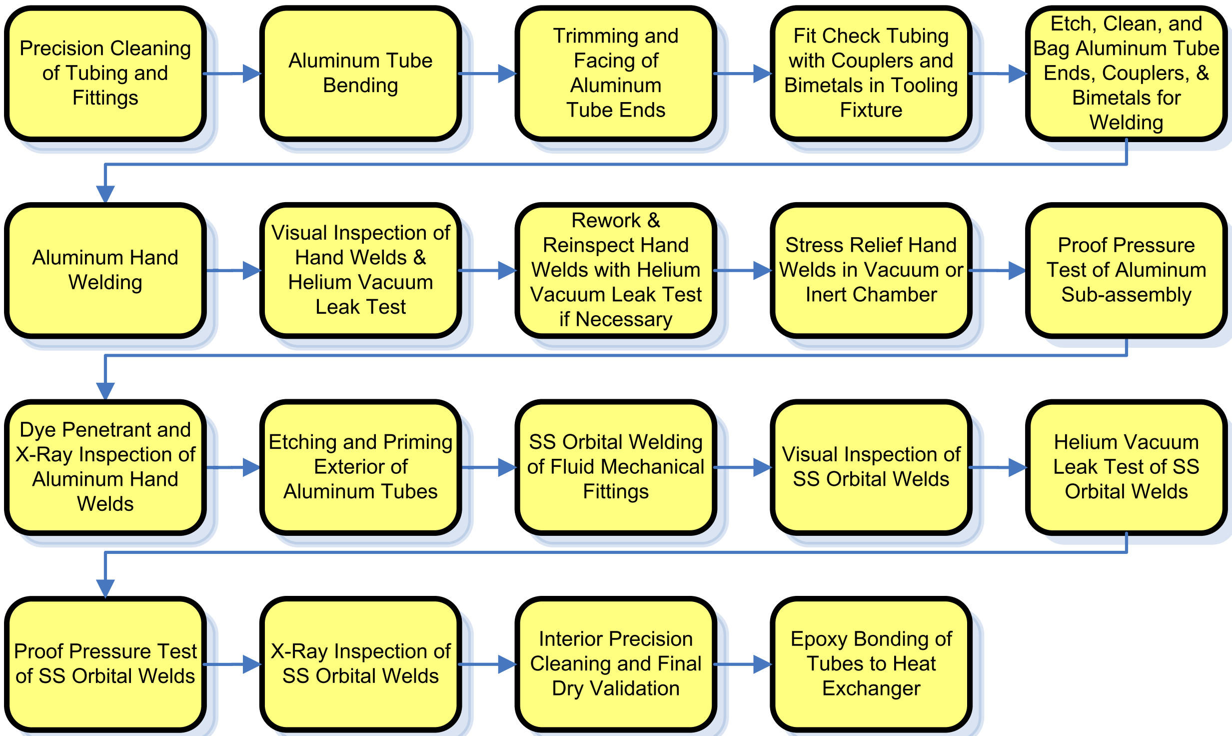


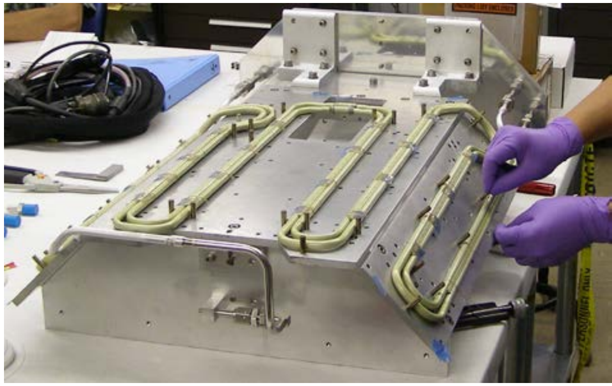
a) Cross Section of Typical Potted Insert Installation

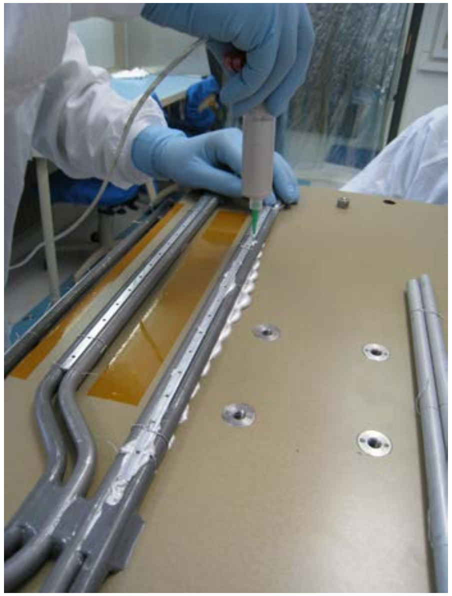
b) Cross Section of Special Potted Insert Installation for Low Through-Panel Thermal Conductivity



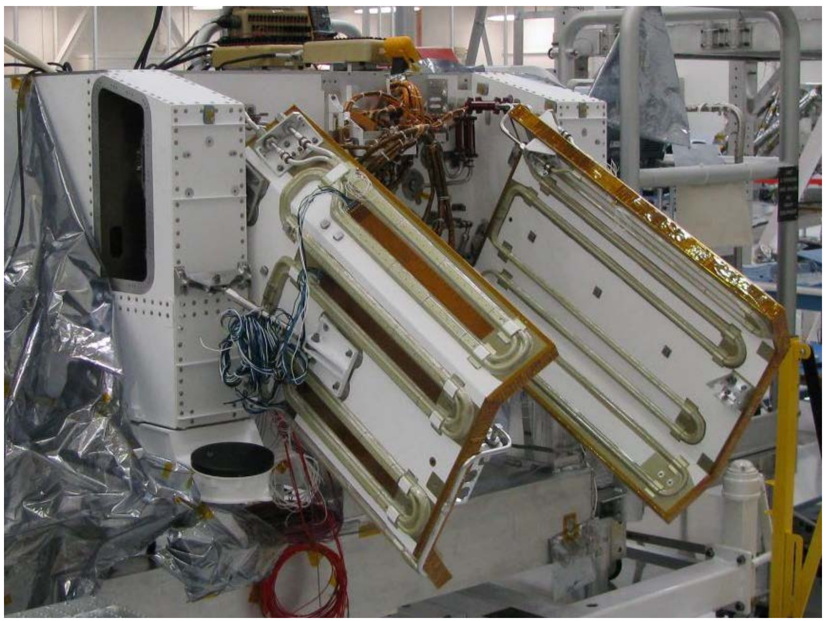
Thermal and Mechanical Design of Heat Rejection System (HRS) Tubing



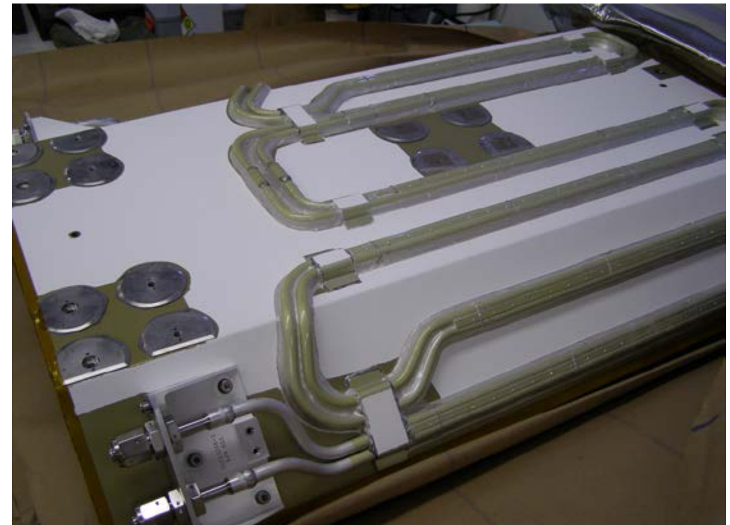




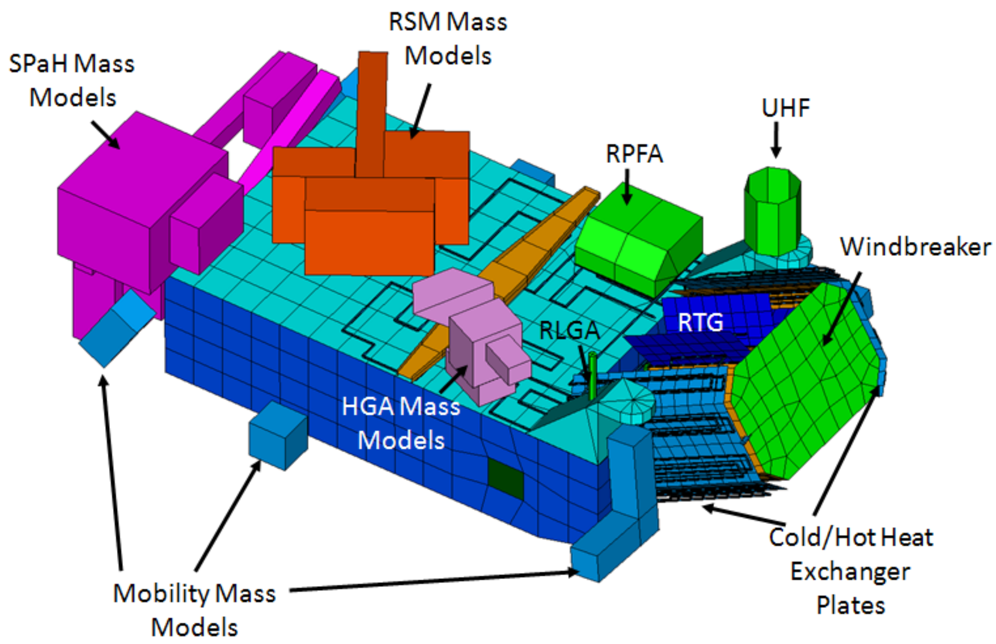
Completed Heat Exchanger Assemblies

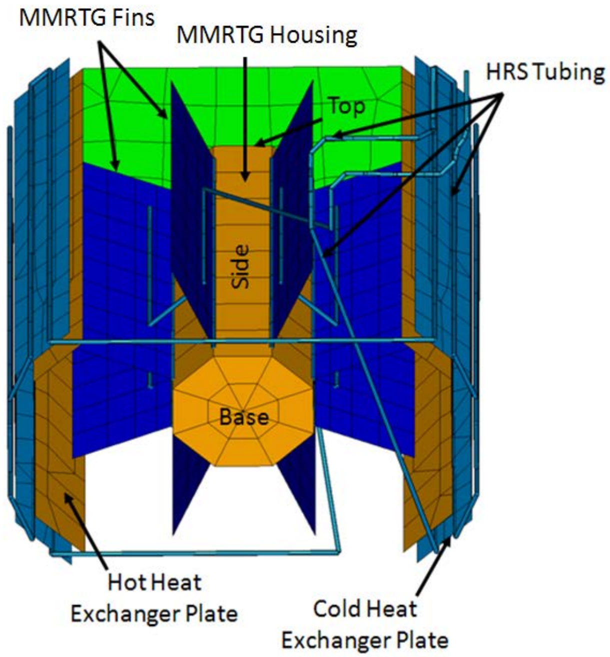


Installed on Rover Aft Chassis Panel



Thermal Model of Rover Heat Exchanger Assemblies



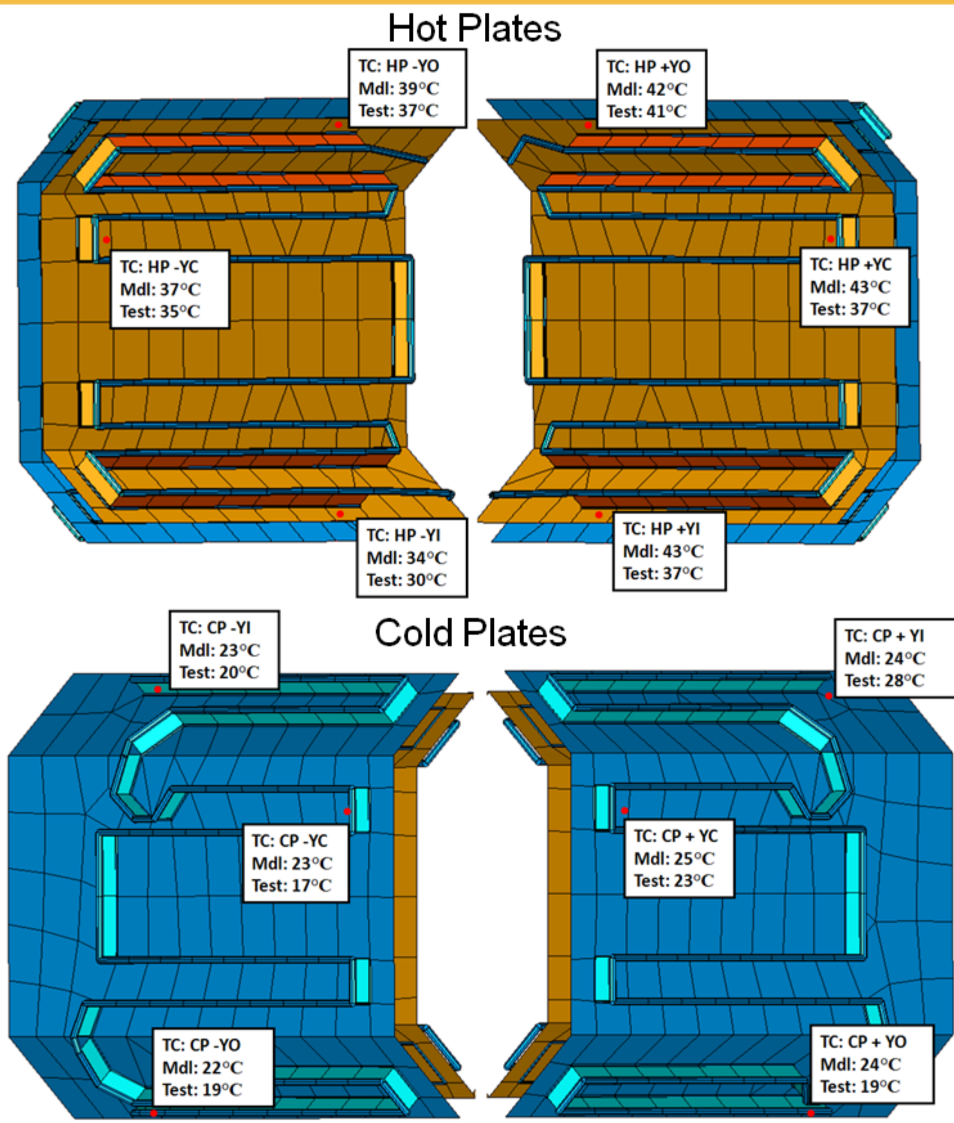


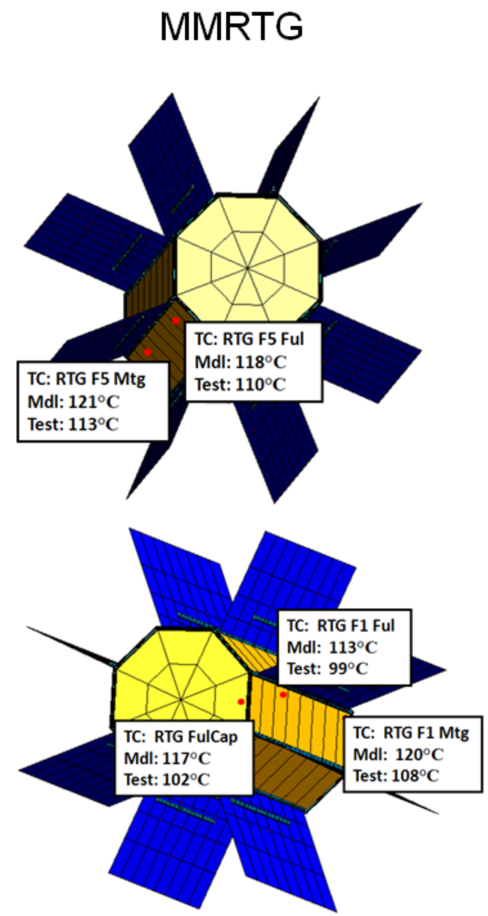
I-DEAS TMG Model

Cruise Phase System Level Thermal Vacuum Test at JPL

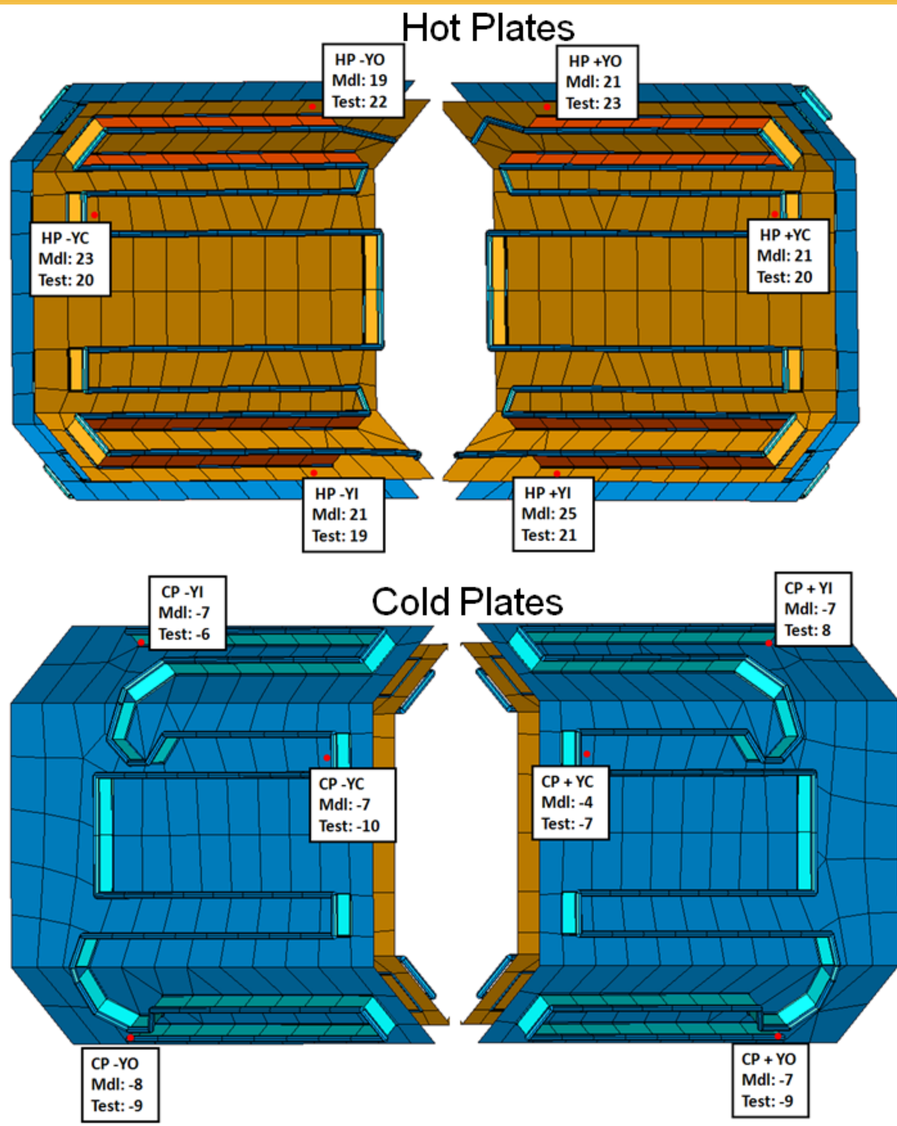
- Performed at JPL during February 2009
- Simulated MMRTG plus electronics dissipation (2100 W)

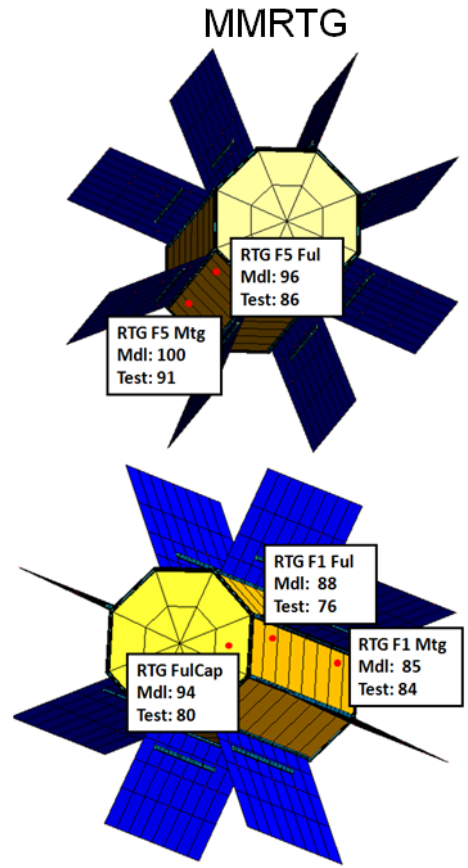
Thermal Model Predictions versus Test Data: Hot Case (Near Earth)



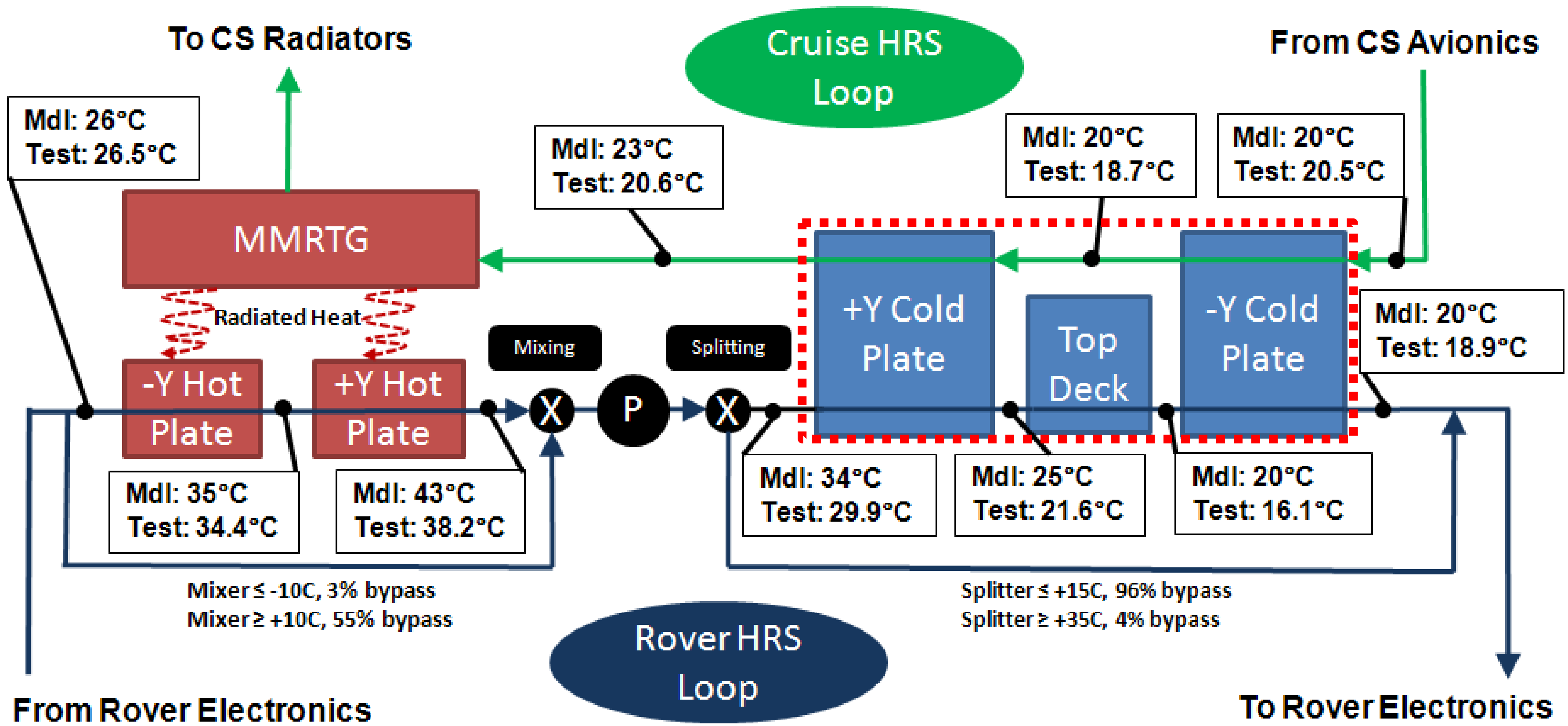


Thermal Model Predictions versus Test Data: Cold Case (Near Mars)





Thermal Model Predictions versus Test Data: Hot Case (Near Earth)



Observation: Minimal liquid to liquid heat transfer between the Rover and Cruise Loops

Conclusions

- In general there was good correlation between the thermal model and test data
- Although Cruise to Rover Loop Heat Exchanger design (Thermal Wedge implementation) not that critical, this was most robust option to carry forward during early design phase.
- Several challenging design constraints were overcome and various tests confirmed that the HXs exceeded the thermal and mechanical requirements with adequate margins

Acknowledgements

The development described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The authors express their thanks to the Mars Science Laboratory Rover project sponsored by NASA for supporting this effort. The authors also wish to thank several of their colleagues at JPL who were instrumental to making the HXs a reality: Saverio D'Agostino, Dustin Crumb, Joe Mora, Vinnie Dang, Jim Dodge, Bill Castillo, Ray Higuera, David Soules, Shaun Stott, Jerry Gutierrez, Tuan Nguyen, Curtis Tucker, Chris Porter, Poyan Bahrami, Lou Luong, Choon Ng, Michael Saeger, Arseola Peacock, Eric Oakes, Bill Pearson, John Guest, Mike Fine, and Lon Chen. Mauro Prina and Brenda Hernandez (currently at Space X, Hawthorne, California) supported this task before leaving JPL in 2008. The authors also thank Jackie Lyra, MSL Thermal Subsystem Product Delivery Manager, for her support and encouragement during the course of this task and several vendors who supported the fabrication of the HXs including Astropak, CedTech, Eric Robinson of Omnisafe, One Way Manufacturing, and Aviation Equipment.

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