Thermal Design Overview of the Mars Exploration Rover Project

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Agenda

- Mission Overview
- Thermal Environments
- Driving Thermal Requirements
- Thermal Design Approach
- Thermal Control Block Diagram
- Thermal Design Description
- Thermal Analysis Results Summary
- Testing Plans
- Issues & Concerns
Flight System Configuration

Flight System

- Cruise Stage
- Backshell
- Heat Shield
- Lander
- Rover

1.7 m
2.65 m
MER-A Cruise Scenario

View from Ecliptic North Pole
20 Day Tic Marks

**MER-A**
Launch Date = 5/30/03
Arrival Date = 1/4/04

**MER-B**
Launch = 6/25/03
Arrival = 1/25/04

- **z axis**
  - antenna boresight
  - panel normal axis
  - spin axis

90° cone around -z axis
  - ±45° offset antenna
  - ±45° panel normal axis

Entry attitude 1/4/04
- z to Earth = 24°
- z to Sun = 63°

1/4/04
SPE = 42°
SEP = 88°

Vernal equinox

8/26/03
SPE = 2°
SEP = 176°

**Mars Exploration Rover**

Earth at launch 6/3/03
1.48 AU

Mars at launch 6/3/03
1.14 AU

Earth at Landing 1/4/04

Mars at landing 1/4/04
- z to Earth = 24°
- z to Sun = 63°

L+1, 6/4/03
SPE = 98°

7/9/03
SPE = 60°

8/26/03
SPE = 2°
SEP = 176°
**Entry, Descent & Landing (EDL) Scenario**

- **Entry Turn & HRS Freon Venting:** E- 70m
- **Cruise Stage Separation:** E- 15m

**Entry:** E- 0 s, 125 km, 5.7 km/s, $\gamma =$ -11.5 deg.

**Parachute Deployment:** E+ 295 s, 11.8 km, 430 m/s

**Heatshield Separation:** E+ 315 s

**Lander Separation:** E+ 325 s

**Bridle Deployed:** E+ 335 s

**Radar Ground Acquisition:** L- 18 s

**TCM-5:** E-12 hrs. Concurrent with EDL, but commanded from ground.

- **Airbag Inflation:** 355 m, L - 10.1 s
- **Rocket Firing:** L- 7 s, ~150 m, 90 m/s
- **Bridle Cut:** L- 3 s, ~20 m
- **Deflation:** L+20 min
- **Roll-Stop:** L+2 min
- **Petals & SA Opened:** Bounces + L+90 min
- **Landing:** ~E+420 s
- **Airbags Retracted:** GTT-4

**Landing Times (Mars local solar time):**
- **MER-A:** ~2:30PM
- **MER-B:** ~12:30PM
- **Earthset:** ~3:30PM
Impact to Egress Scenario

Sol 1
Solar Array Deploy
PMA Deploy & Imaging
HGA Deploy

Sol 2-3
Petal / Airbag Adjustments
Pancam/Mini-TES

Sol 4
Drive Petals to final Configuration
Release Middle Wheels & Fire 3rd Cable Cutter
Turn in Place
Drive Off Lander Deck

GTT- 5
**Location 4**


**Location 3**


**Location 2**


**Location 1**


**Landing Site**


Sols 17-21: Drive to new location.

Reference: 2S Hematite Scenario for MERB
Cruise Stage Configuration

- Cruise Shunt Radiator
- LGA
- 2X Sun Sensors
- MGA rotated ~90°
- Thruster Cluster
- Sun Sensor Electronics
- HRS Radiators
- PDM Location
- CEM
- Star Scanner
- (2) Composite Tanks
- Shunt Limiter
- Integrated Pump Assembly

Not shown:
- Lighting Suppression Assembly
Lander Assembly - Stowed

- +y Petal (panel 1)
- +x Petal (panel 2)
- Cabling Pulley Assy
- Shroud (3 places)
- Monopole UHF Antenna (stowed)
- -x Petal (panel 3)
- DEA coax
- Cable Tray
- Backside of Rover
- Solar Array
- Latch Covers
- Sep Nut Subass’y
- Gas Generator (3 places)
- Lander Petal Actuator (3 places)

Airbag Envelope (4 places)

Radar Antenna Bracket

Rover Wheel

Airbag Retraction Actuator (4 places)

Not shown: Egress Aids
Lander Assembly - Deployed

ARA (4 Places, Typ.)
Power LEM
Rover Cabling
Rover Lift Mechanism
DRL
Bridle
+Y PETAL
Parachute Roller (3 Places, Typ.)
Shear Panel
LPA (3 Places, Typ.)
Radar Electronics
Radar Altimeter Bracket
BIP/Lander Sep Nut (6 Places, Typ.)
Gas Generator (3 Places, Typ.)
Avionics LEM
Primary Battery Packages
LPSA
LPA (3 Places, Typ.)

GTT-11
Shaded Isometric Views of the Stowed Rover
Deployed Rover on the Lander

- Low Gain Antenna
- High Gain Antenna
- Gimbal
- Deployed PMA with New Mast Deployment Drive
- UHF Monopole Antenna
- Solar Arrays with 5 deployed Panels
- Pancam Calibration Target
- Low Profile Wheel Restraints
Rover Configuration - Deployed

- Navcams
- Pancams
- Pancam Mast Assembly (PMA)
- Magnets
- Rover Equipment Deck (RED)
- Instrument Deployment Device (IDD)
- Calibration Target
- Low Gain Antenna (LGA)
- UHF Monopole Antenna
- High Gain Antenna (HGA)
- Solar Arrays
- Warm Electronics Box (WEB)
- Mobility Differential
- Mobility System
Isometric View of the WEB

- IMU
- UHF Radio
- Rear Cable Tunnel and Bulkhead
- 1/2" Seapnut WEB Restraint to Lander
- X-Band SDST
- Differential Shaft Connection to the Starboard Rocker Bogie
- X-Band SSPA
- Forward Cable Tunnel and Bulkhead
- X-Band Waveguide to HGA
- REM Structure and Electronic Slices
- GTT-16
Pancams - Mast mounted stereo panoramic cameras with color filters on pan/tilt gimbal
- 1024x1024x12bit CCD
- ~16deg FOV

Mini-TES - Miniature Thermal Emission Spectrometer
- Near and mid-IR point spectrometer (6 to 25 μm with resolution of 10 cm⁻¹) to determine mineralogy of Martian surface
- 20/8 mrad FOV raster scanned to produce thermal emission “images”
In situ Science Instruments

- Instrument Deployment Device (IDD) - a 5 DOF robotic arm for deployment of 3 in situ science instruments and a Rock Abrasion Tool (RAT) against rock and soil targets
  - Microscopic Imager (MI) - 1024x1024x12bit camera with 30 µm/pixel resolution with 3 mm depth of field
  - Alpha Particle X-ray Spectrometer (APXS) - determine elemental chemistry of target
  - Moessbauer Spectrometer (MB) - detects nanophase and amorphous hydrothermal Fe minerals, identifies Fe carbonates, sulfates, nitrates, and determines oxidation state of Fe minerals

- The front HAZCAMs provide imaging of workspace for ground planning of instrument deployments
Instrument Deployment Device (IDD)

Magnet

Moessbauer Spectrometer (opposite side)

Rock Abrasion Tool

HAZCAMs

Alpha Particle X-ray Spectrometer

Microscopic Imager

Mars Exploration Rover
Rock Abrasion Tool (RAT)

- Penetrates through dust & surface alteration that might be present on rocks, exposing materials more likely to preserve evidence of environmental conditions at the time of their formation.
Thermal Environment

- Off-sun during cruise requirements:
  - Continuous: 0° to 51° off-sun cone angle
    - Launch to Launch + 21 days: up to 51°
    - Launch + 22 day to Mars turn-to-Entry: 0° to 46°
  - Transient off-sun cone angles & durations
    - TCM1: 90° for up to 110 minutes at 1.02 AU
    - Mars turn-to-Entry: 83° for up to 70 minutes

![Graph showing off-sun cone angles and durations relative to heliocentric distance.]

Region of continuous duration

Heliocentric distance, AU

Off-sun cone angle, degrees
• **Mission requirements** (encompasses MER-A & MER-B):
  - Cruise Heliocentric distance: 1.01 AU to 1.52 AU
  - Areocentric longitude during surface operations ($L_s$): 328 to 40°
  - Landing site: 15S to 10N
  - Surface operations duration: 90 Sols

• **Mars surface environmental requirements** (MER ERD, Rev A):
  - Surface temperature (min/max): -97°C / 26°C
  - Atmosphere temperature (min/max): -95°C / 2°C
  - Solar flux at the surface (min/max): 0 / 600 W/m²
  - Sustained wind speed at 1 m above surface:
    - 8:00 LST to 17:00 LST: 3 to 15 m/s
    - 17:00 LST to 8:00 LST (next day): 0 to 15 m/s
    - Wind speed at elevations below 1m will be less
Key Driving Level 3 Requirements

• Driving allowable flight temperature (AFT) requirements:
  – REM avionics/telecom maximum (op & non-op) AFT limit: 50°C
    • Limiting factor for DTE requirement & nighttime battery energy usage
    • Drives need for heat rejection system (HRS)
    • Drives EDL thermal design
  – Rover battery - operating AFT limits: -20/30°C
    • Tighter temperature limits than REM governed RHU & thermal switch usage for Martian surface operation
  – Lander battery - cruise storage (non-op) AFT limits: -40/10°C
    • Tightest limits of all non-HRS controlled hardware
  – Backshell IMU maximum operating AFT limit: 51°C
    • Constrains operation at launch (for calibration purposes) & during EDL
  – Propellant line minimum (op & non-op) AFT limit: 15°C
Key Driving Level 3 Requirements (cont’d)

- Surface communication requirements:
  - 2 hours of continuous DTE operation per Sol and up to 3 total hours per Sol

<table>
<thead>
<tr>
<th>DOORS ID</th>
<th>Requirement</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>888</td>
<td>The Thermal Control System shall maintain all specified flight hardware within the limits listed in the Temperature Requirements Table for 2 hrs of continuous DTE X-band per sol, starting no later than 11:00am and for 3 hr total of DTE X-band transmission per sol, subject to availability of power</td>
<td>Comply by design &amp; analysis</td>
</tr>
</tbody>
</table>

- Capability to operate the HGA actuators at 10 am Mars local time without additional warm-up heater

<table>
<thead>
<tr>
<th>DOORS ID</th>
<th>Requirement</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>607</td>
<td>The Flight System shall be capable of operating the HGA actuators at 10 am Mars local time without additional warmup.</td>
<td>Comply by design &amp; analysis</td>
</tr>
</tbody>
</table>

Blue text denotes changes from Project PDR
System Thermal Block Diagram
Cruise Stage Thermal Design Overview

Sun Sensors:
Ag/FEP tape on top

HRS Radiators:
M1 (white) paint on both sides

MGA:
S13-GLO (white) paint on back

LVA:
S13-GLO (white) paint on lateral side

Solar Array:
Ag/FEP tape on inner ring, S13-GLO (white) paint on substrate backside

Cruise Shunt Radiator:
M1 (white) paint including sep. spring covers, anodized L/V spring pads
Cruise Stage Thermal Design Overview
(cont’d)

- **PDM**: MLI & thermostatic heaters
- **Sun Sensor Elect.**: MLI & Outward Ag/FEP Radiator
- **CEM**: MLI & Outward Ag/FEP Radiator
- **Star Scanner**: MLI & thermostatic heater
- **TCAs**: MLI & thermostatic heaters
- **CSL Radiator**: S13-GLO (white) paint
- **CSL**: Controlled by HRS
- **HRS Vent Outlet**: Warm-up heater
- **IPA**: MLI & HRS
- **Intercostals**: S13-GLO (white) white paint
- **Propellant Tanks**: MLI & thermostatic heaters
- **Propellant Lines**: MLI, aluminum cladding, thermostatic FSW heater control for 8 zones
IVSR consists of:
- IVSR structure
- IPA
- 2 Pyro valves
- Filter in parallel with a relief valve
- Vent outlet
- Pressure transducer
- CSL heat exchanger
- CSL “shark fin” radiator

Rover cable cutter
HRS flex tubing
BIP cable cutter
HRS radiator (12)
• Mars Pathfinder IPA shown

• MER adopted a Mars Pathfinder build-to-print approach for the IPA
IPA Schematic

GAS FLOW THROUGH PYRO VALVE TO PURGE LIQUID CFC 11 FROM HRS

CFC 11 TO PYRO VALVE FOR VENT TO SPACE

GAS FILL PORT

ACCUMULATOR

INLET

PURGE PORT

PUMP/MOTOR “A”

PUMP/MOTOR “B”

THERMAL VALVE

CHECK VALVE

OUTLET

BYPASS OUTLET

FILL PORT
Lander Thermal Design Overview

ARA (4)
Low $\alpha/s$ finish
Warm-up heaters

Power LEM
Thermostatic heaters

LPSA
Thermostatic heaters

LPA (3)
Low $\alpha/s$ finish
Warm-up heaters

RA Electronics
(2 Places, Typ.)
Radar Altimeter
Bracket

Gas Generator (3)
Warm-up heaters

Rover Lift Mechanism
Warm-up heater

Rover Wheel Cabling

BIP/Lander
Sep Nut (6 Places, Typ.)

Avionics LEM
Thermostatic heaters

Battery Package (5)
Thermostatic heaters

LPA Electronics (3)
Commandable heaters

Parachute Roller
(3 Places, Typ.)

Shear Panel

DRL
Bridle

+Y PETAL

-X PETAL

GTN- 33
Rover Thermal Design Overview

PMA
- Mast actuator warm-up heaters
- Camera electronic warm-up heaters
- Camera filter wheel warm-up heaters
- Low $\alpha/\varepsilon$ finish on mast & camera actuators

SHAG
- Actuator warm-up heater
- Low $\alpha/\varepsilon$ finish on actuator

IDD
- Actuator warm-up heaters

Mobility
- Actuator warm-up heaters
WEB DESIGN FEATURES

- Aerogel attached to interior of WEB structure
- Thermostatic heaters on battery, REM, & mini-TES
- Thermal switches for battery
- HRS tubing on REM for cruise

Battery Radiators (2)  
RHU holder
Thermal Switches (2)  
Battery Assembly
HRS tubing on REM
Thermal Switch

- Heat switch assembly:
  - Heat switch unit
    - Passive, variable thermal conductance mechanism which is mounted between the radiator & RHU holder on Rover battery
    - Variable conductance achieved via temperature activated paraffin wax which expands/contracts to mechanically close/open the switch
  - Wobblefram seal
    - Teflon PFA diaphragm used to seal off hole in WEB wall
<table>
<thead>
<tr>
<th>CRUISE STAGE</th>
<th>ALLOWABLE FLIGHT</th>
<th>PREDICTED FLIGHT</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OP</td>
<td>NOP</td>
<td>OP</td>
</tr>
<tr>
<td></td>
<td>min</td>
<td>max</td>
<td>min</td>
</tr>
<tr>
<td>Cruise Solar Array average</td>
<td>-50</td>
<td>90</td>
<td>-70</td>
</tr>
<tr>
<td>Cruise Shunt Limiter Assembly</td>
<td>-25</td>
<td>40</td>
<td>n/a</td>
</tr>
<tr>
<td>Propellant Tanks (includes gas service valves)</td>
<td>15</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>Tanks during ground operations</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Thruster Valve, 1 lbf</td>
<td>20</td>
<td>110</td>
<td>20</td>
</tr>
<tr>
<td>PDM</td>
<td>15</td>
<td>50</td>
<td>15</td>
</tr>
<tr>
<td>service valve outside PDM make it a unit</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>pressure transducer</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>CEM Assembly</td>
<td>-40</td>
<td>50</td>
<td>-40</td>
</tr>
<tr>
<td>Star Scanner head &amp; electronics</td>
<td>-14</td>
<td>50</td>
<td>n/a</td>
</tr>
<tr>
<td>Sun Sensor electronics</td>
<td>-30</td>
<td>50</td>
<td>n/a</td>
</tr>
<tr>
<td>Sun Sensor Heads (2 on -Z, 3 on XY)</td>
<td>-25</td>
<td>85</td>
<td>n/a</td>
</tr>
<tr>
<td>5/8&quot; Ti Bolt, Bushing &amp; Sep. Spring</td>
<td>-60</td>
<td>60</td>
<td>-60</td>
</tr>
<tr>
<td>IPA</td>
<td>-20</td>
<td>40</td>
<td>-20</td>
</tr>
<tr>
<td>IPA electronics</td>
<td>-20</td>
<td>50</td>
<td>-20</td>
</tr>
<tr>
<td>Pyro valve-HRS purge</td>
<td>-30</td>
<td>66</td>
<td>-30</td>
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<tr>
<td>HRS radiator</td>
<td>-90</td>
<td>n/a</td>
<td>n/a</td>
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<tr>
<td>Cruise Shunt Radiator</td>
<td>-40</td>
<td>100</td>
<td>-40</td>
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<tr>
<td>LVA</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

**Note:** vendor code 'GTT' is 37.
## Cruise Thermal Analysis - Aeroshell

**Temperature (°C)**

<table>
<thead>
<tr>
<th>AEROSHELL</th>
<th>ALLOWABLE FLIGHT</th>
<th>PREDICTED FLIGHT</th>
<th>Margin</th>
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<tbody>
<tr>
<td></td>
<td>OP (min, max)</td>
<td>NOP (min, max)</td>
<td>OP (min, max)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NOP (min, max)</td>
</tr>
<tr>
<td>BIP:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/8&quot; Cable Cutter (BIP)</td>
<td>-100 30 -100 60</td>
<td>n/a n/a -34 9</td>
<td>n/a n/a n/a n/a</td>
</tr>
<tr>
<td>1&quot; Cable Cutter in (BIP)</td>
<td>-100 30 -100 60</td>
<td>n/a n/a -34 9</td>
<td>n/a n/a n/a n/a</td>
</tr>
<tr>
<td>5/8&quot; Pyro Sep Nut, Cruise Stage Sep. (BIP)</td>
<td>-100 30 -100 60</td>
<td>n/a n/a -34 9</td>
<td>n/a n/a n/a n/a</td>
</tr>
<tr>
<td>Parachute Canister &amp; Mortar</td>
<td>-45 45 -45 45</td>
<td>n/a n/a -35 9</td>
<td>n/a n/a n/a n/a</td>
</tr>
<tr>
<td>Backshell:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BS Thermal Batteries</td>
<td>-40 35 -40 35</td>
<td>n/a n/a -29 6</td>
<td>n/a n/a n/a n/a</td>
</tr>
<tr>
<td>Backshell Pyro Switch Assembly (BPSA)</td>
<td>-40 50 -40 50</td>
<td>n/a n/a -29 0</td>
<td>n/a n/a n/a n/a</td>
</tr>
<tr>
<td>IMU-Liton LN 200S (Rover &amp; Backshell)</td>
<td>-39 51 -47 65</td>
<td>n/a n/a -29 -1</td>
<td>n/a n/a n/a 18</td>
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<tr>
<td>3/8&quot; Pyro Sep Nut, B/S side</td>
<td>-120 30 -120 60</td>
<td>n/a n/a -94 3</td>
<td>n/a n/a n/a n/a</td>
</tr>
<tr>
<td>3/8&quot; Ti Bolt &amp; Sep Mech. (LMA Supplied)</td>
<td>-120 30 -120 60</td>
<td>n/a n/a -94 3</td>
<td>n/a n/a n/a n/a</td>
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<td>RAD Rockets</td>
<td>-40 -20 -40 40</td>
<td>n/a n/a -24 2</td>
<td>n/a n/a n/a n/a</td>
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<tr>
<td>TIRS Motors</td>
<td>-40 -20 -40 40</td>
<td>n/a n/a -24 5</td>
<td>n/a n/a n/a n/a</td>
</tr>
<tr>
<td>Backshell-outer surface (TPS)</td>
<td>-150 n/a -150 n/a</td>
<td>n/a n/a -36/-97</td>
<td>n/a n/a n/a 114/53</td>
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<tr>
<td>Backshell-Bond line</td>
<td>-100 150 -100 150</td>
<td>n/a n/a -35/-95</td>
<td>n/a n/a n/a n/a 64/5</td>
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<tr>
<td>Heatshield:</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Heatshield-outer surface (SLA561)</td>
<td>-150 n/a -150 n/a</td>
<td>n/a n/a -81 -7</td>
<td>n/a n/a n/a n/a</td>
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<tr>
<td>Heatshield-Bond line</td>
<td>-150 250 -150 250</td>
<td>n/a n/a -81 -6</td>
<td>n/a n/a n/a n/a</td>
</tr>
</tbody>
</table>
# Cruise Thermal Analysis - Lander

## TEMPERATURE (°C)

<table>
<thead>
<tr>
<th>Component</th>
<th>ALLOWABLE FLIGHT</th>
<th>PREDICTED FLIGHT</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OP min</td>
<td>OP max</td>
<td>NOP min</td>
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<tr>
<td>Descent antenna</td>
<td>-110</td>
<td>45</td>
<td>-110</td>
</tr>
<tr>
<td>Radar Altimeter Xmit Antennas</td>
<td>-85</td>
<td>45</td>
<td>-85</td>
</tr>
<tr>
<td>Radar Altimeter Rec Antennas</td>
<td>-85</td>
<td>45</td>
<td>-85</td>
</tr>
<tr>
<td>Radar Altimeter electronics</td>
<td>-40</td>
<td>40</td>
<td>-40</td>
</tr>
<tr>
<td>Coax Transfer switch (CXS4)</td>
<td>-35</td>
<td>50</td>
<td>-35</td>
</tr>
<tr>
<td>Lander Primary Battery (LiSO2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cruise (non-op)</td>
<td>n/a</td>
<td>n/a</td>
<td>-40</td>
</tr>
<tr>
<td>Lander Pyro Switch Assembly (LP SA)</td>
<td>-50</td>
<td>50</td>
<td>-50</td>
</tr>
<tr>
<td>Power-LEM Assembly</td>
<td>-40</td>
<td>50</td>
<td>-50</td>
</tr>
<tr>
<td>Avionics-LEM Assembly</td>
<td>-40</td>
<td>50</td>
<td>-50</td>
</tr>
<tr>
<td>3/8&quot; Release Nuts</td>
<td>-120</td>
<td>30</td>
<td>-120</td>
</tr>
<tr>
<td>5/8&quot; Lander Cable Cutter</td>
<td>-105</td>
<td>30</td>
<td>-105</td>
</tr>
<tr>
<td>1&quot; Cable Cutter w/HRS on Base Petal</td>
<td>-105</td>
<td>30</td>
<td>-105</td>
</tr>
<tr>
<td>Lander Petal Actuator (+Y, +X -X)</td>
<td>-45</td>
<td>15</td>
<td>-105</td>
</tr>
<tr>
<td>Airbag Retraction Actuator (+Y, +X -X base petal)</td>
<td>-45</td>
<td>15</td>
<td>-105</td>
</tr>
<tr>
<td>Rover Deploy (lift) Actuator Assembly</td>
<td>-45</td>
<td>15</td>
<td>-105</td>
</tr>
<tr>
<td>Airbag material, cruise</td>
<td>n/a</td>
<td>n/a</td>
<td>-85</td>
</tr>
<tr>
<td>Gas Generator (+Y, +X -X)</td>
<td>-40</td>
<td>0</td>
<td>-50</td>
</tr>
<tr>
<td>Bridle cutter assy (B/S)</td>
<td>-120</td>
<td>30</td>
<td>-120</td>
</tr>
<tr>
<td>Bridle Descent Rate Limiter</td>
<td>-55</td>
<td>30</td>
<td>-55</td>
</tr>
<tr>
<td>Bridle Assy</td>
<td>-60</td>
<td>30</td>
<td>-60</td>
</tr>
<tr>
<td>Lander Structure</td>
<td>-55</td>
<td>40</td>
<td>-55</td>
</tr>
</tbody>
</table>

**Margin**

- OP: Allowable Flight Operation
- NOP: Predicted Flight No Operation
- Min: Minimum
- Max: Maximum

GTT-39
### Cruise Thermal Analysis - Rover

<table>
<thead>
<tr>
<th></th>
<th>ALLOWABLE FLIGHT</th>
<th>PREDICTED FLIGHT</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OP</td>
<td>NOP</td>
<td>OP</td>
</tr>
<tr>
<td></td>
<td>min</td>
<td>max</td>
<td>min</td>
</tr>
<tr>
<td>R O V E R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSPA</td>
<td>-25</td>
<td>50</td>
<td>-40</td>
</tr>
<tr>
<td>SDST</td>
<td>-25</td>
<td>50</td>
<td>-40</td>
</tr>
<tr>
<td>UHF Transceiver</td>
<td>-40</td>
<td>55</td>
<td>-40</td>
</tr>
<tr>
<td>Rover Solar Array (3J)</td>
<td>-125</td>
<td>90</td>
<td>-125</td>
</tr>
<tr>
<td>Li-Ion Battery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cruise</td>
<td>-20</td>
<td>10</td>
<td>n/a</td>
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<tr>
<td>REM Assembly</td>
<td>-40</td>
<td>50</td>
<td>-40</td>
</tr>
<tr>
<td>Web Structure</td>
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</tr>
<tr>
<td>WEB Bumper Limit Switches</td>
<td>-105</td>
<td>50</td>
<td>-105</td>
</tr>
<tr>
<td>Solar Array Bumper Limit Switches</td>
<td>-105</td>
<td>50</td>
<td>-105</td>
</tr>
<tr>
<td>RHU</td>
<td>-100</td>
<td>300</td>
<td>n/a</td>
</tr>
<tr>
<td>S C I E N C E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mini TES</td>
<td>-40</td>
<td>35</td>
<td>-40</td>
</tr>
<tr>
<td>IMU-Litton LN 200S (Rover &amp; Backshell)</td>
<td>-39</td>
<td>51</td>
<td>-47</td>
</tr>
</tbody>
</table>

GTT- 40
Rover 2 Hour of Continuous DTE

SSPA, SDST, IMU, Battery Case, Mini-TES Temperatures - 4hr off, 2hr on DTE, No LHP, Batt/Wax Switches (SP=18C), Hot Environment (Ls=328, Lat=-15S, Ti=250, Tau=0.2, Albedo=0.14), 4hr DTE Early MER A Power Profile

Max SSPA Interface Temp = 51°C
Max UHF Interface Temp = 52°C
Max Battery Temp = 26°C
Rover Cold Surface Scenario

MER_D Model: SSPA, SDST, IMU, Battery Case, Mini-TES Temperatures
SSPA LHP (Sp=20.0C), Batt Wax Switches (SP=18C), Cold Environment
(Ls=16, Lat=-15S, Tl=250, Tau=0.2, Albedo=0.28), Minimum "Loss of
Communication" Power Profile (373Whr)
Subsystem Test Plans

- Rover/HRS Thermal Characterization Test Overview
  - Test start delayed (11/15/01 → 2/23/02) due to EM H/W delivery slip (10/1/01 → 1/18/02)
  - 30 day test is performed in Bldg. 248 10-foot vertical chamber
  - Test article is a combination of EM & TMM H/W (no flight H/W)
  - This is a preview of the integrated system thermal performance
    - Identify & correct potential thermal design defects prior to system thermal test
    - Examine HRS performance during cruise
    - Examine WEB/RED & thermal switch performance for Mars landed environment
Subsystem Test Plans (cont’d)

- System T/B Test Overview
  - S/C Cruise 1  9/10/02  B150 25’ chamber  12 days
  - S/C Cruise 2  11/5/02  B150 25’ chamber  5 days
  - Rover 1       1/10/03  B248 10’ chamber  12 days
  - Rover 2       1/22/03  B248 10’ chamber  5 days

- First & third tests are thermal design verification
  - No thermal margin testing planned

- Second & fourth tests are workmanship tests

- IR lamps used in B150 25’ chamber for off-sun environmental heating during cruise

- IR lamps used in B248 10’ for Mars solar environmental heating during landed operations
<table>
<thead>
<tr>
<th>Issue/Concern</th>
<th>Resolution Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difficult to quantify uncertain parameters for BS IMU thermal analysis. Absolute worst-case results only permit 60 minutes of operation</td>
<td>Review analysis &amp; assumptions to determine if a realistic worst-case can be confidently established. If so, determine if IMU operational time is acceptable. If not, inform Systems that only 60 minutes of operation is permissible.</td>
</tr>
<tr>
<td>Issue/Concern</td>
<td>Resolution Plan</td>
</tr>
<tr>
<td>------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Schedule for Rover thermal vacuum/thermal balance tests too close to one another to permit assessment of test data &amp; to institute design fixes, if necessary</td>
<td>Work with ATLO to inject sufficient margin between both Rover tests.</td>
</tr>
<tr>
<td>Separate flight lander test not part of ATLO thermal test baseline</td>
<td>Currently carried as a reserve request. Consider a descoped test where: Lander is tested in a smaller chamber OR only critical elements are tested.</td>
</tr>
</tbody>
</table>