Wax Actuated Heat Switch Development for Mars Exploration Rover

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Overview

- Background
- Key Driving Requirements
- Mars Exploration Rover (MER) Application – Rover Battery
  - Rover Battery Thermal Control System
  - Thermal Control System Performance
- Paraffin Actuated Heat Switch
  - Heat Switch Design Features
  - Heat Switch Performance
  - Flight Qualification
- Summary

MER Project Description

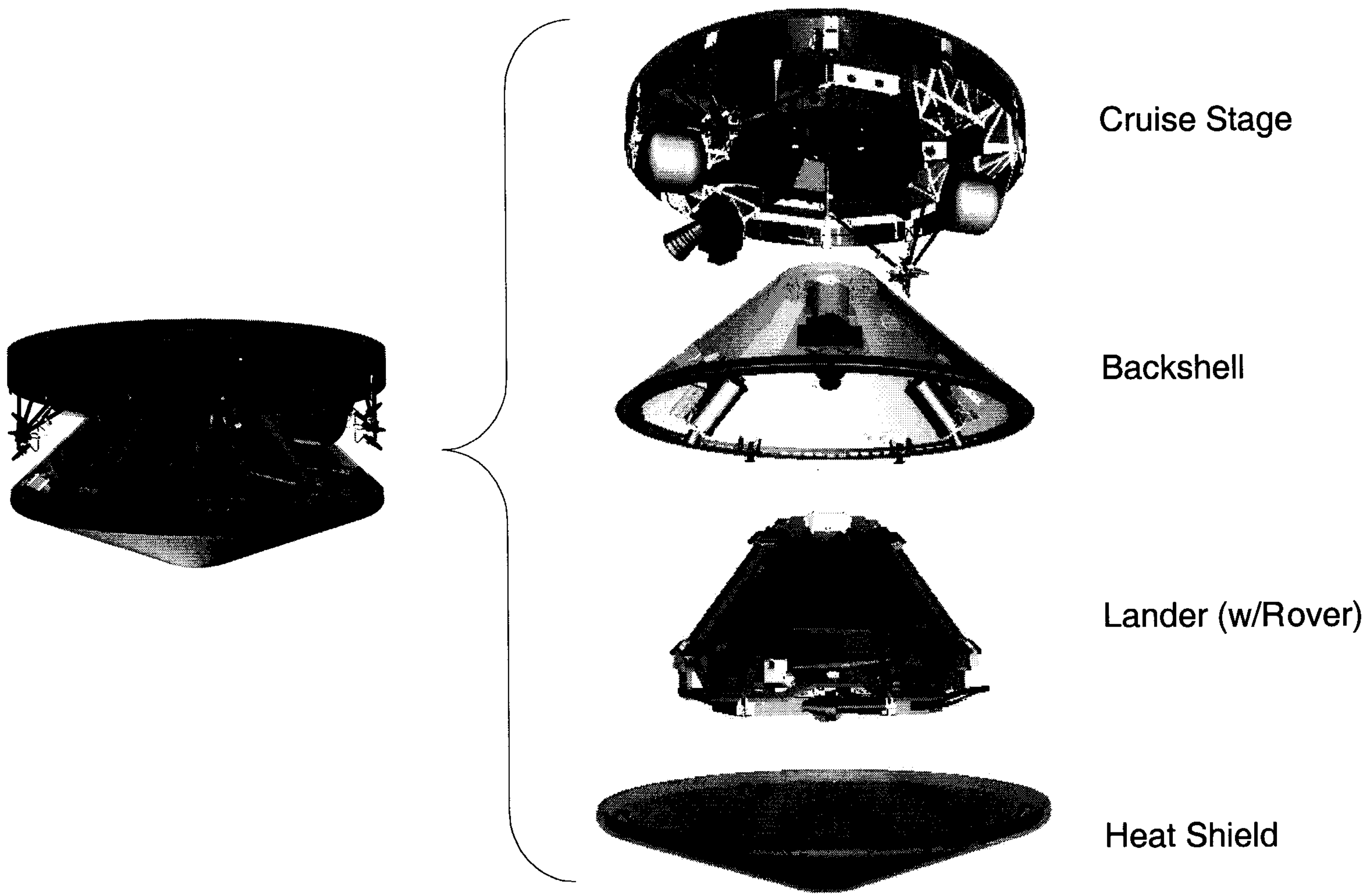
- The Mars Exploration Rover (MER) is a mission to land two identical rovers on Mars and perform in situ geological science with a surface operations lifetime of at least 90 sols.

- The missions will launch in the 2003 opportunity (June - July) on separate Delta II class vehicles, land on Mars in 2004 (Jan - Feb), deploy the rovers and conduct surface operations.

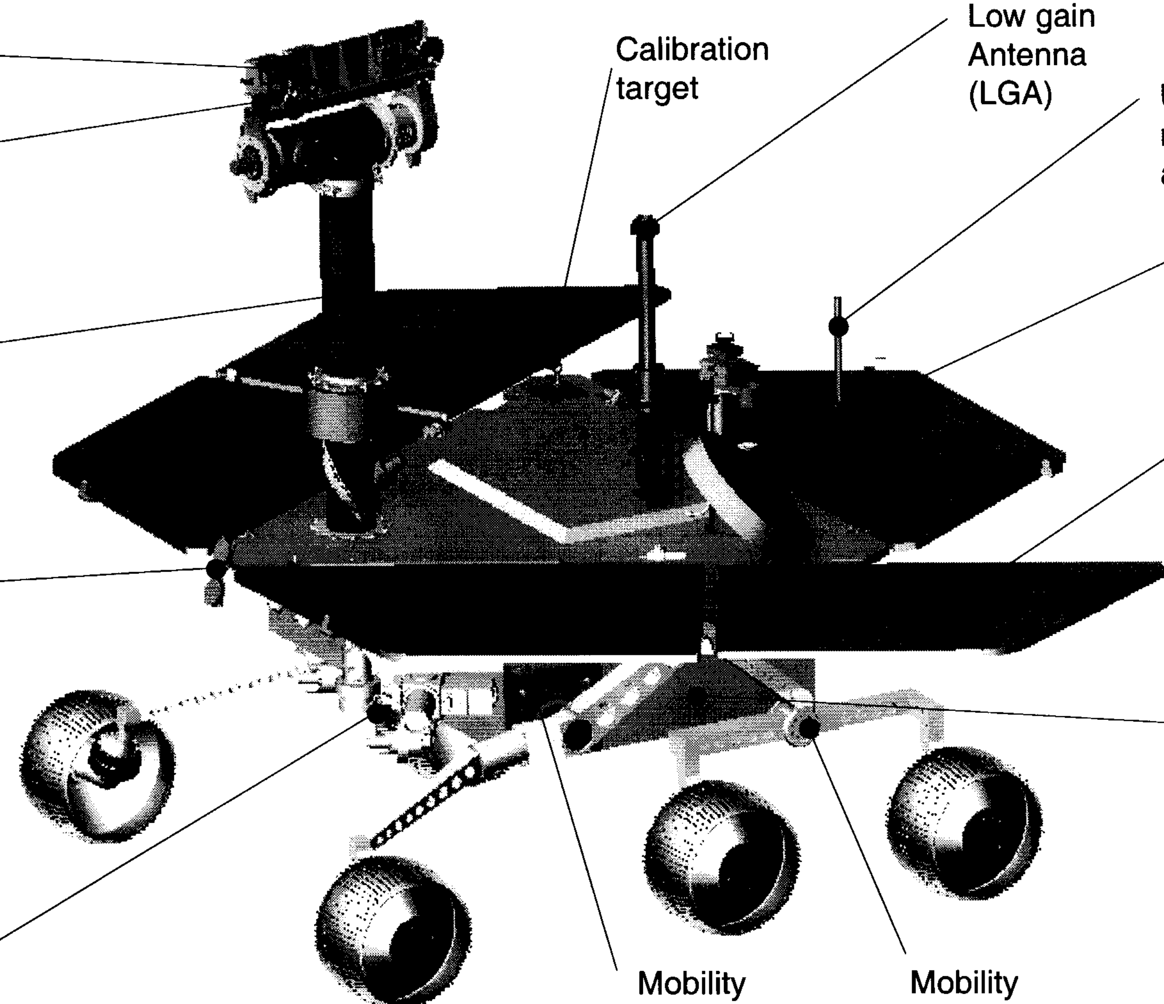
- Each Flight System consists of:

  - A cruise stage and entry, descent and landing system (EDL) with inheritance from Mars Pathfinder (launched in 1996)
  - A rover based upon the Athena Rover developments undertaken for the Mars '01 and Mars Sample Return projects
  - Selected equipment from the Mars '01 lander, including APEX payload elements, SDST, and Cincinnati Electronics UHF radio
  - Athena Science Package

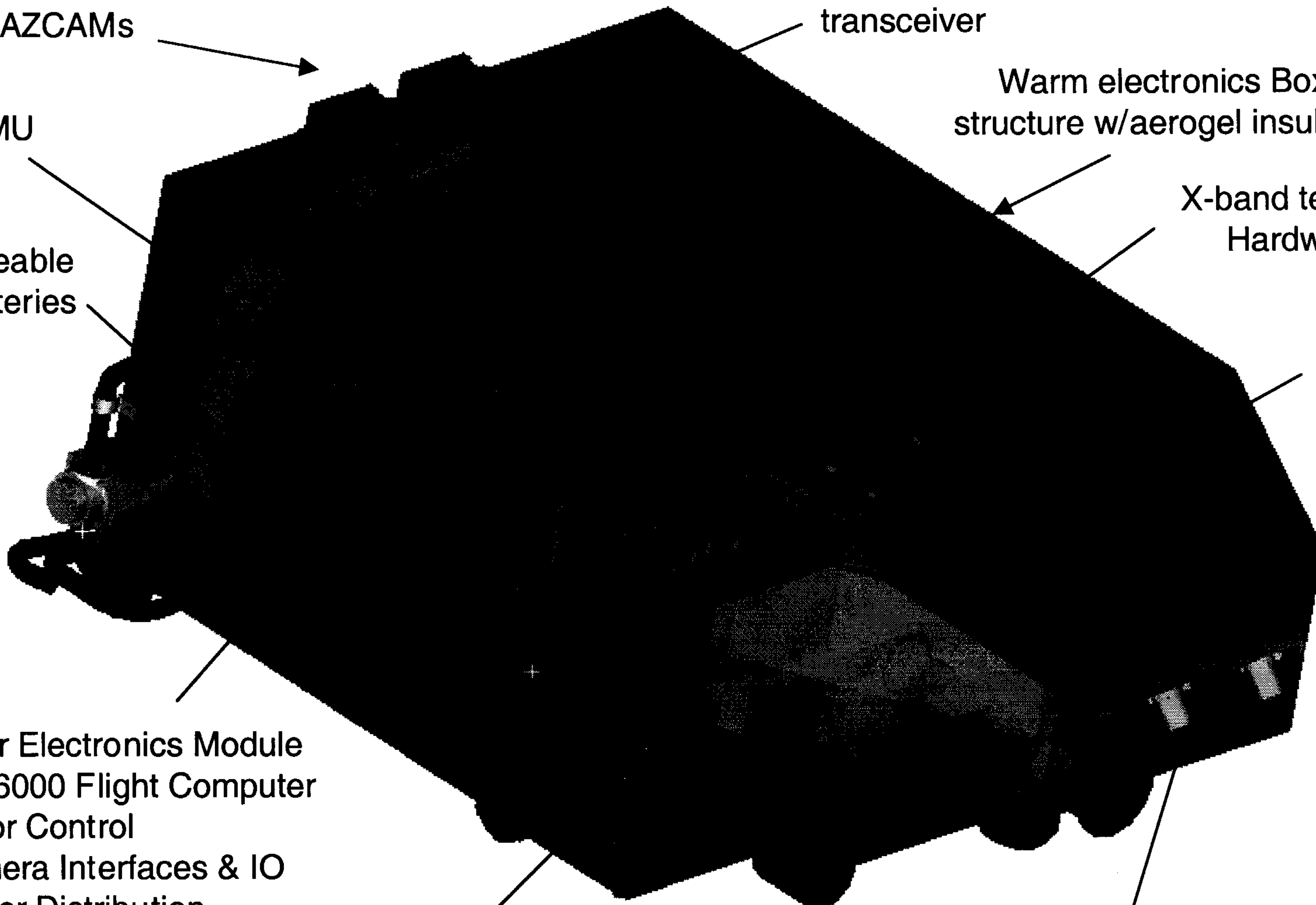
MER Spacecraft Configuration



Rover Configuration - Deployed



Rover Warm Electronics Box



Background

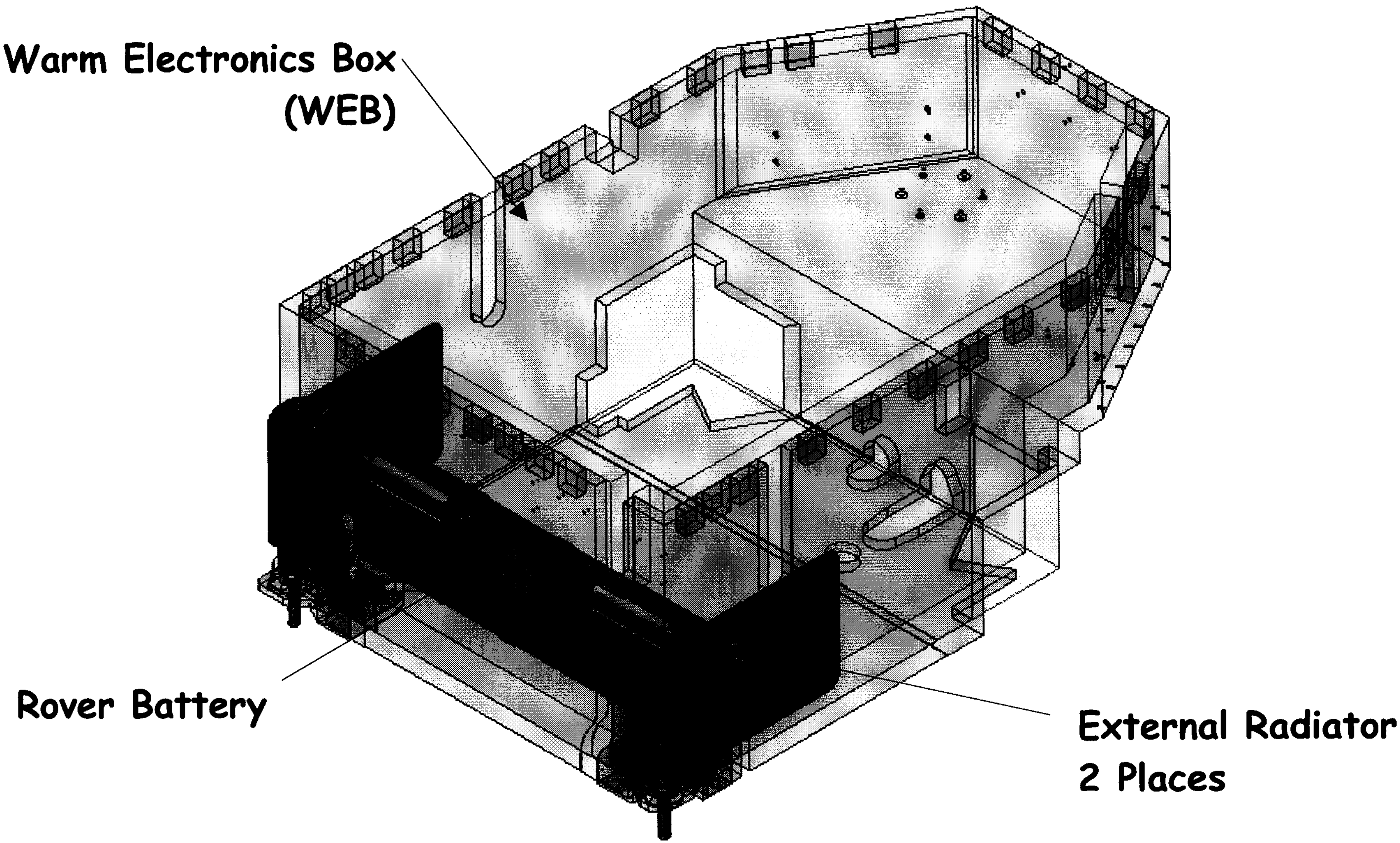
- **Unique Thermal Control Requirements for Mars Surface Applications**
  - Diurnal temperature changes greater than 100 °C Δ
  - Presence of Mars atmosphere (10 torr CO_2)
  - Need to minimize landed mass
  - Electrical Heater Power for active thermal control is scarce
    - Need to conserve energy at night
  - Need to reject or absorb excess heat during the day

- **Driving Req'ts for MER Battery Thermal Control**
  - Extremely narrow allowable flight temperature limits [-20 °C, +30 °C], tightest of all rover hardware
  - Total heat needed to be rejected ~8 to 12W

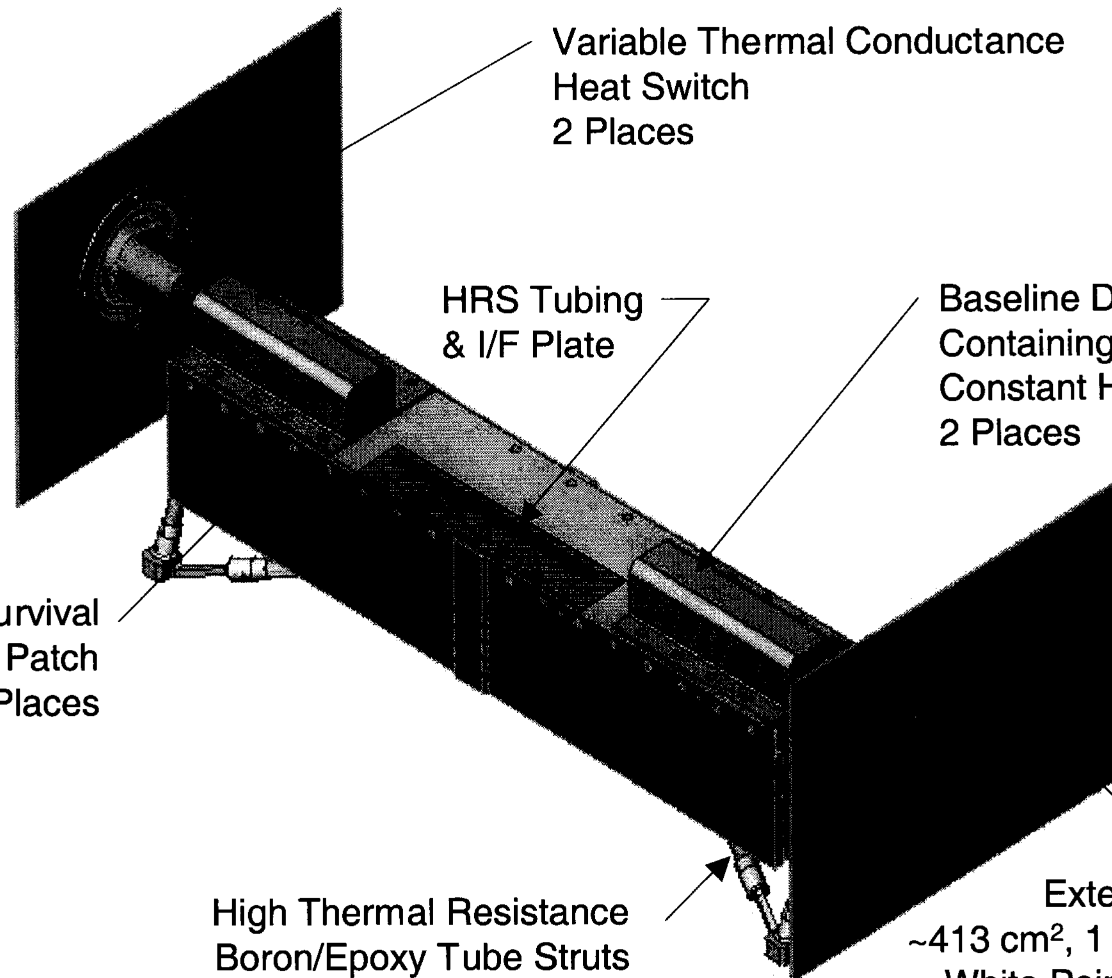
MER Battery Heat Switch

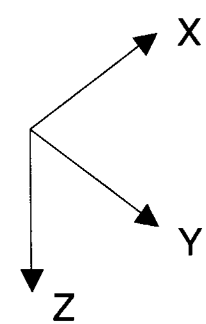
- Heat Switch used for the MER Rover Battery Thermal Control System
  - Battery allowable flight temperature limits:
    - surface ops (discharge): -20 °C to +30 °C
    - surface ops (charge): 0 °C to +30 °C
  - Diurnal environment temperatures:
    - Ground: -100 °C min to +20 °C max
    - Atmosphere: -95 °C min to 0 °C max
    - Sky: -150 °C min to -105 °C max
  - Heat sources
    - Baseline design: RHUs provide 6 W continuous
    - nearby electronics contained within same Warm Electronics Box ~2 to 4W
    - battery internal dissipation – temp dependent
  - Thermostatically controlled survival and warm-up heaters, if necessary

Rover Battery Located in WEB



Mars Exploration Rover (MER) Application





Warm-Up & Survival Mech. Thermostats Mounted to +Z Side of RBAU – Not Shown

Background

- Based on the requirements, a decision was made to use a variable thermal conductance device

- Paraffin Actuated Heat Switch
  - Passive, variable thermal conductance mechanism which can be mounted between a heat sink (external radiator) and heat source (Rover battery assembly)
  - Variable thermal conductance achieved via temperature activated paraffin wax which expands/contracts to mechanically close/open the switch

Key Design Requirements

Requirement Description	Value
Switch-Open Conductance	< 0.018 W/K at 18 ^{o}C and lower
Switch–Closed Conductance	> 0.45 W/K at 25 ^{o}C and higher
Heat Switch Assembly Mass	< 160 g
Landing Loads (qualification)	48 Gs
Random Vibration (qualification)	7.8 Grms, 2 min./axis (20-80 Hz: +6db/Oct. 80-450 Hz: 0.08 G^2/Hz 450-2000 Hz: -6db/Oct.)
Pyroshock (qualification)	100 Hz: 20 g srs 100-1600 Hz: +10 db/Oct. 1600-10000 Hz: 2000 g srs

Paraffin Actuated Heat Switch

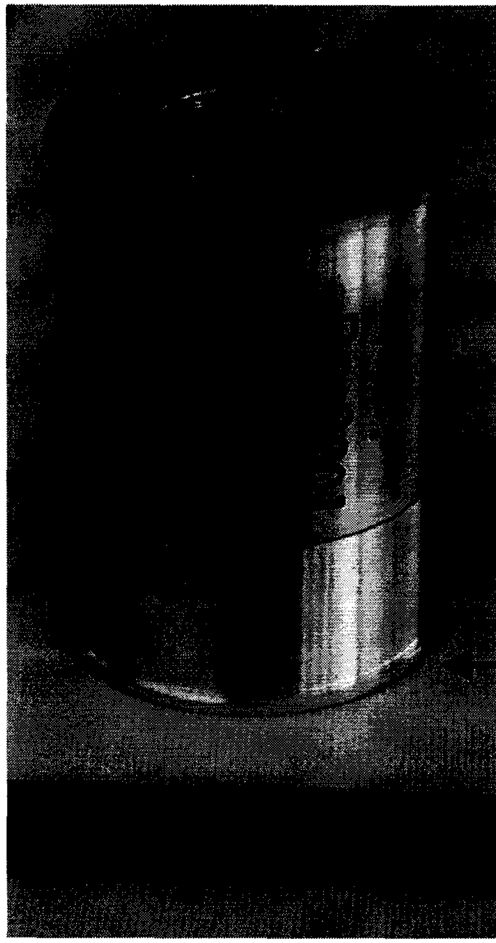
- Design Features
  - Developed by Starsys Research Corporation for JPL
    - Based on previous designs by Starsys with modifications to accommodate the Mars environment
  - About 36 mm diameter x 51 mm in length
  - Aluminum body
  - Entire switch mass ~ 110 grams
  - Molded Viton seal encloses paraffin
  - Temperature based expansion and contraction of the paraffin works to close and open the switch, respectively
    - switch activation temperature is selectable based on paraffin type
  - Springs with insulating stand-offs provide force to open gap when paraffin freezes

Paraffin Actuated Heat Switch

- Design Features (cont'd)
  - Control is not simply by On-Off switching
    - thermal conductance adjusts to stable intermediate levels as required
  - Switch control is based on the temperature of the warm side of the switch
  - In switch-open state, two halves of switch are separated by 1mm gap
    - heat conduction is limited to gas gap conduction and small parasitic leaks through stand-offs
  - In switch-closed state, the halves are pulled into contact with each other
    - heat is conducted through aluminum body across contacting surface

Paraffin Actuated Heat Switch

Heat Switch Shown in Closed State



Attached to heat source

Switch half containing paraffin seal boot

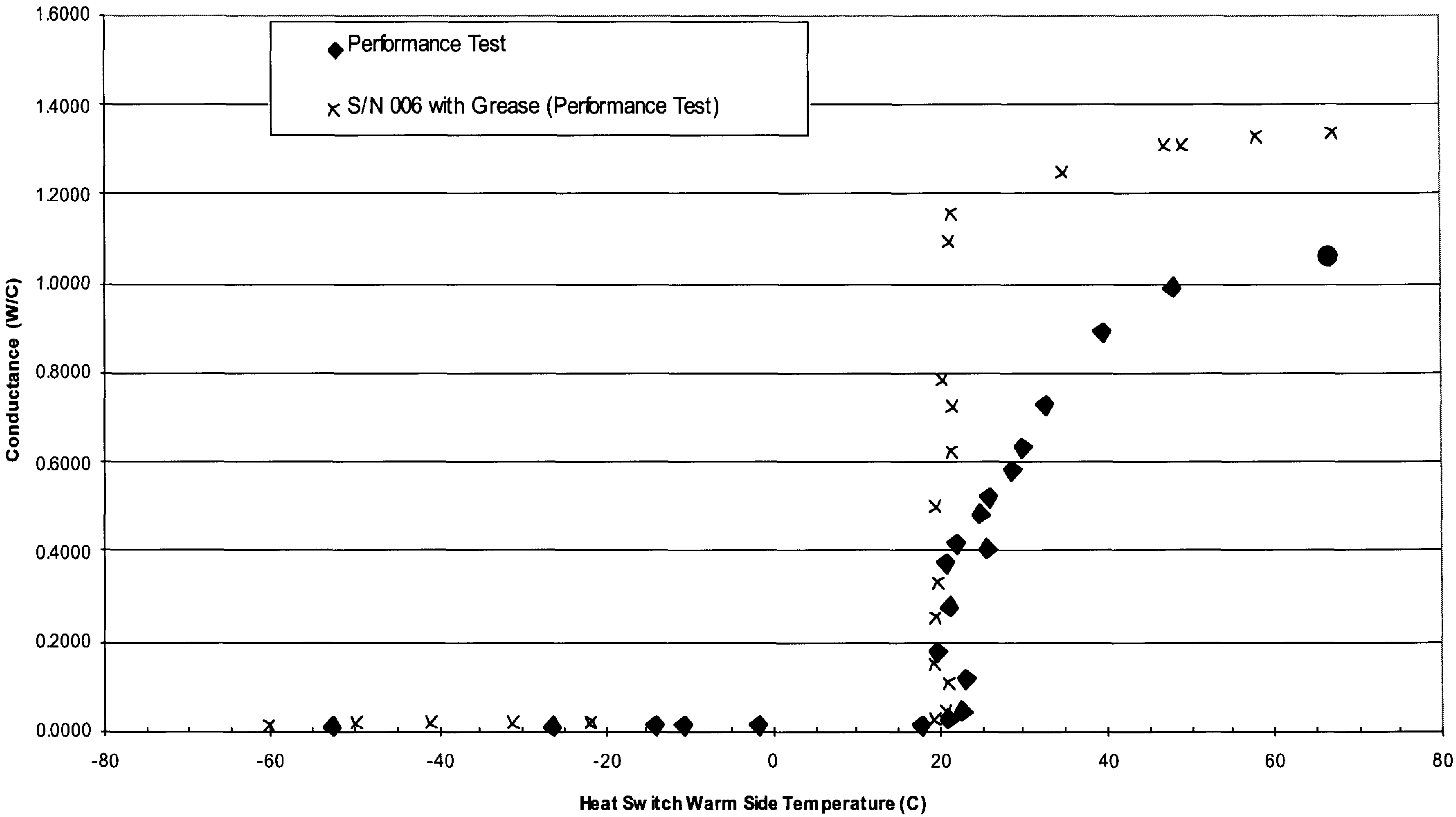
In switch-open state, 1mm gap separates the two switch halves

Attached to radiator

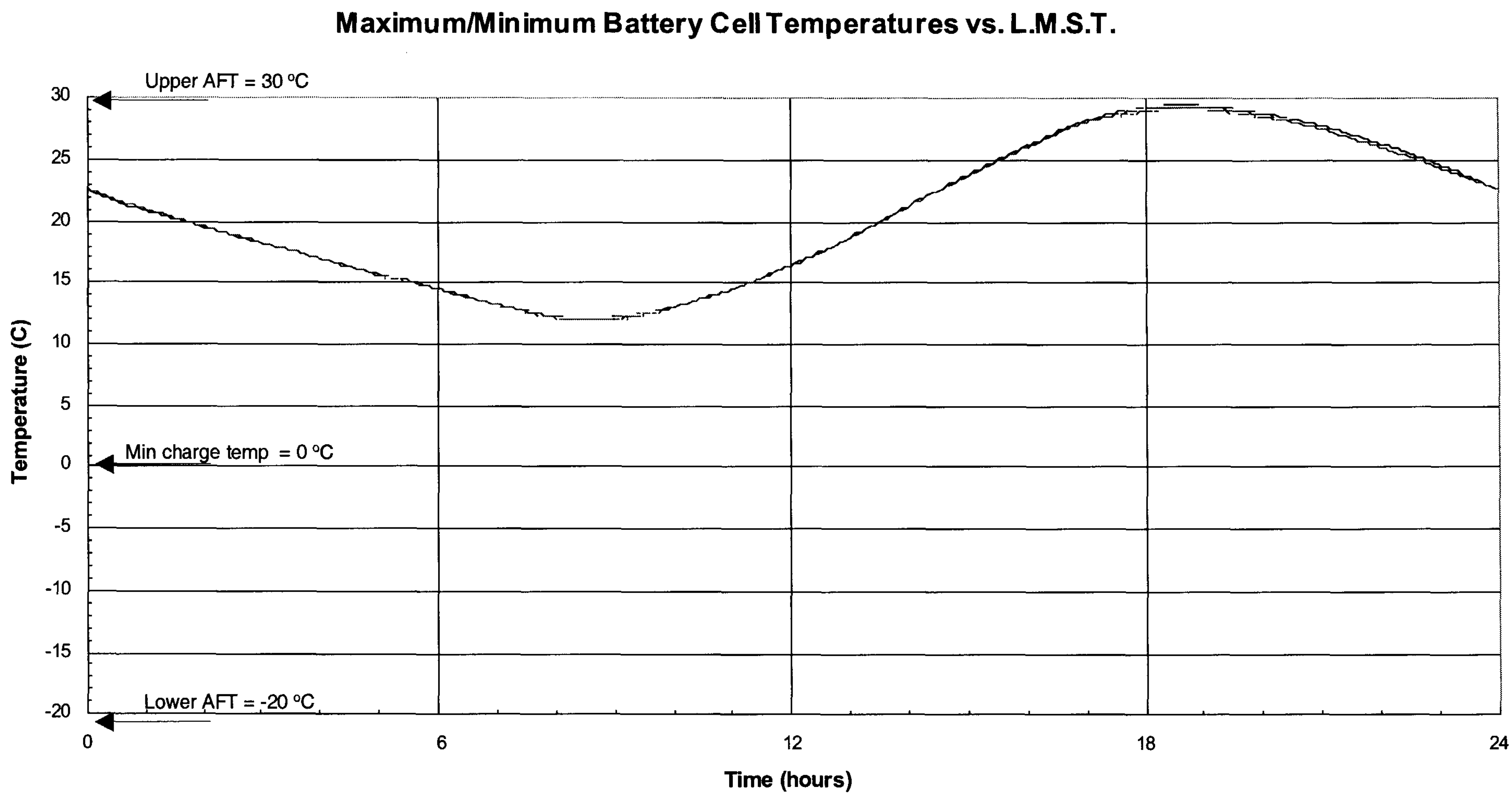
Heat Switch Performance – Grease Plated Interface

Switch

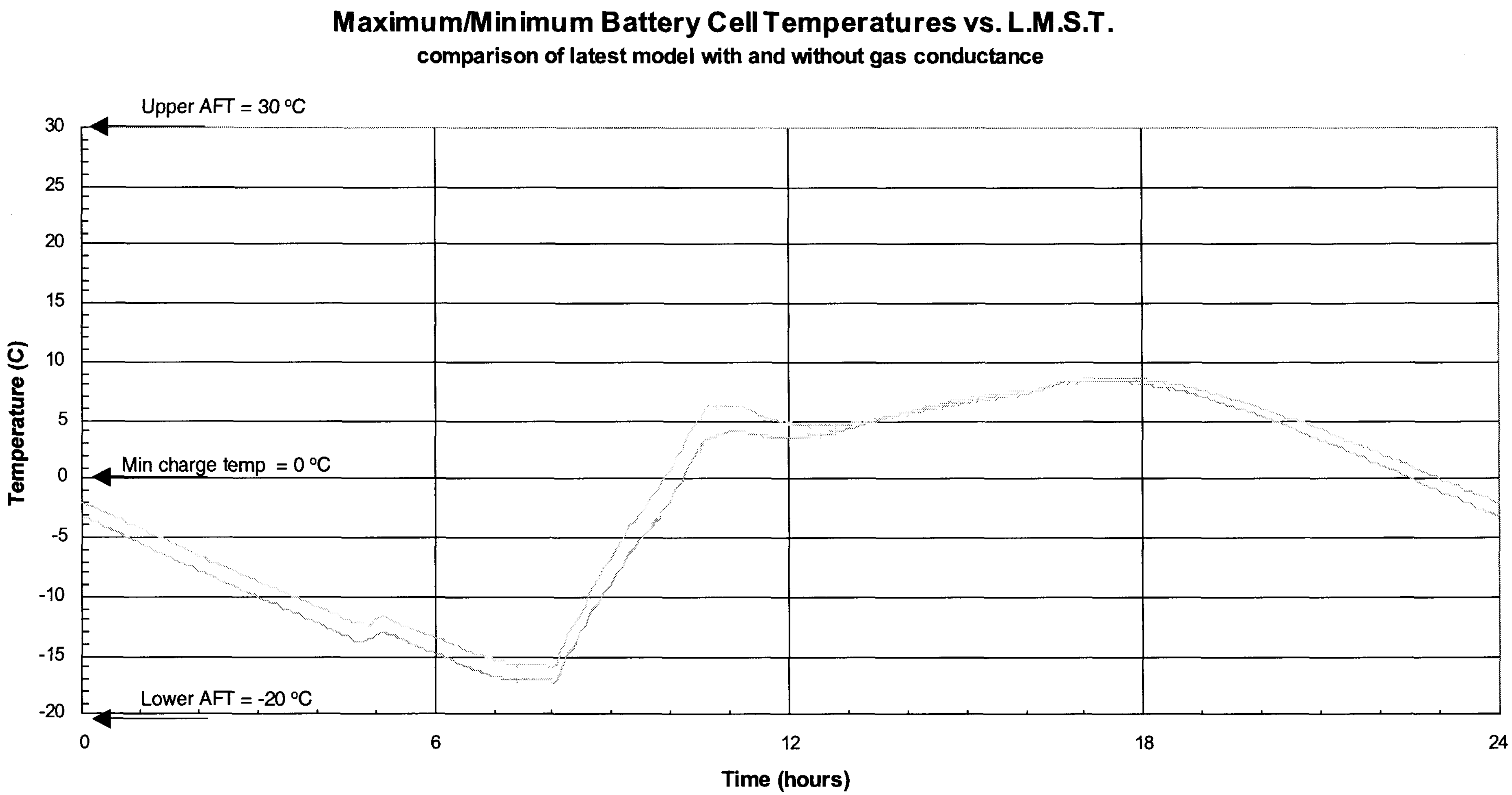
JPL



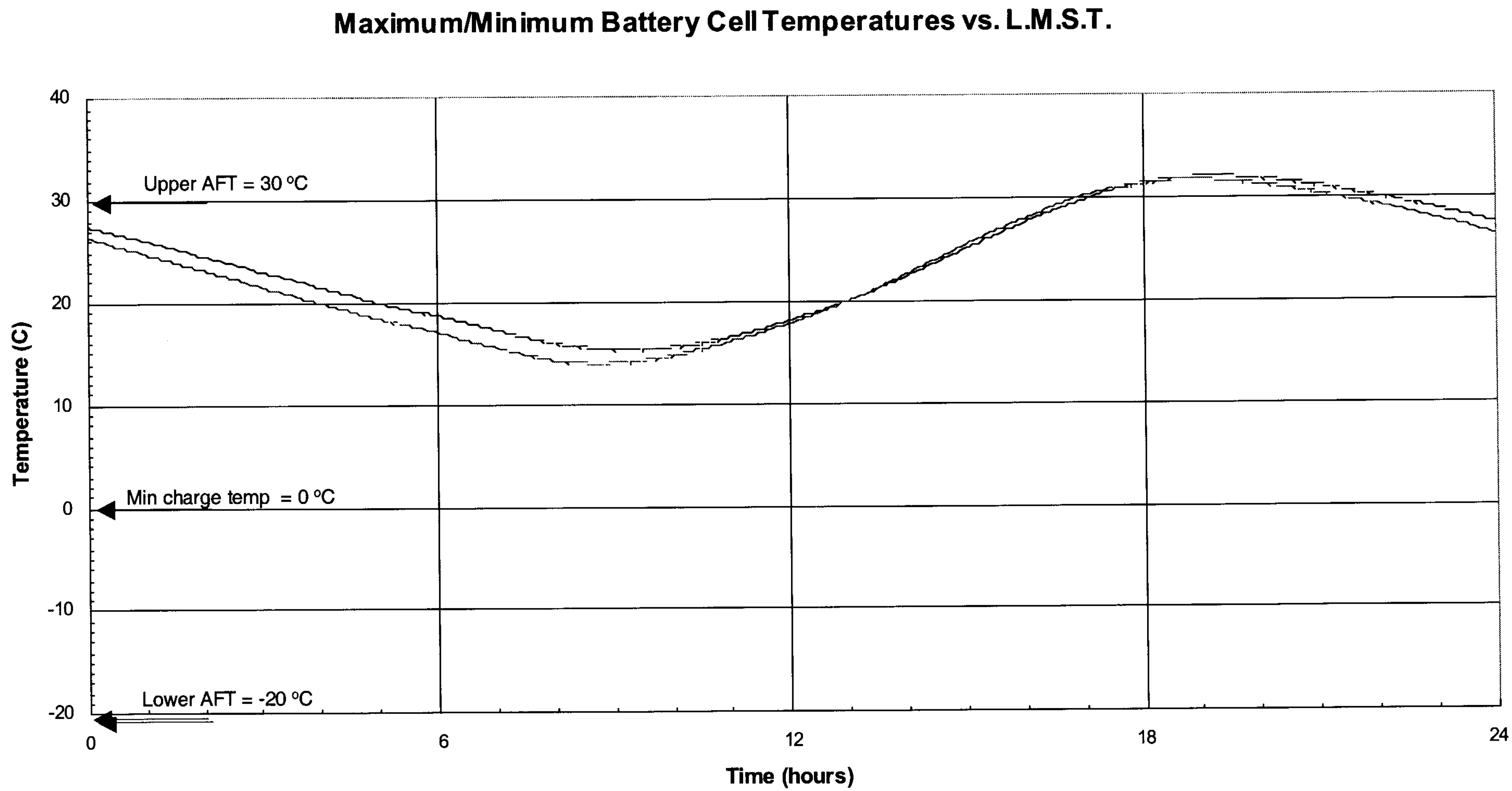
Application Performance – Hot Case Battery Cell Temperature



Application Performance – Cold Case
Battery Cell Temperature



Application Performance – Fault Condition of One Switch Failed Open



Heat switch failed closed unlikely

Summary

- Heat Switch functions autonomously and requires no power
- Heat Switch works well with the relatively low dissipations
- Heat Switch has been flight qualified for use on the Mars Exploration Rover (Mid-2003 Launch)
  - Thermal performance exceeds requirements
  - Robust structural design permitted Switch to survive landing loads twice the requirement
- Flight units currently undergoing acceptance testing at Starsys