Development Testing of a Paraffin-Actuated Heat Switch for Mars Rover Applications

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OUTLINE

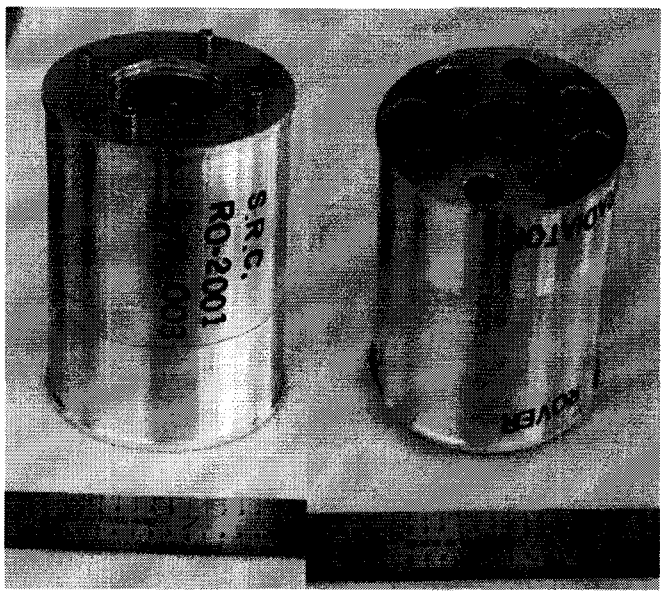
- Heat Switch Design Requirements for Landed Mars Missions
- Description of Prototype Heat Switch
- Development Test Program
- Discussion of Test Results
- Conclusions

Heat Switch Design Requirements for Landed Mars Missions

- The Heat Switch must operate in the extreme Martian environment.
- The cold side must survive a temperature range of –100° to +30°C for at least 100 diurnal cycles
- The hot side must operate over a temperature range of -20° to +30°C
- Closed thermal conductance must exceed 0.45W/°C at 25°C.
- Open thermal conductance must be less that 0.018 W/°C
- Must withstand landing loads up to 48-g.

Description of the Heat Switch

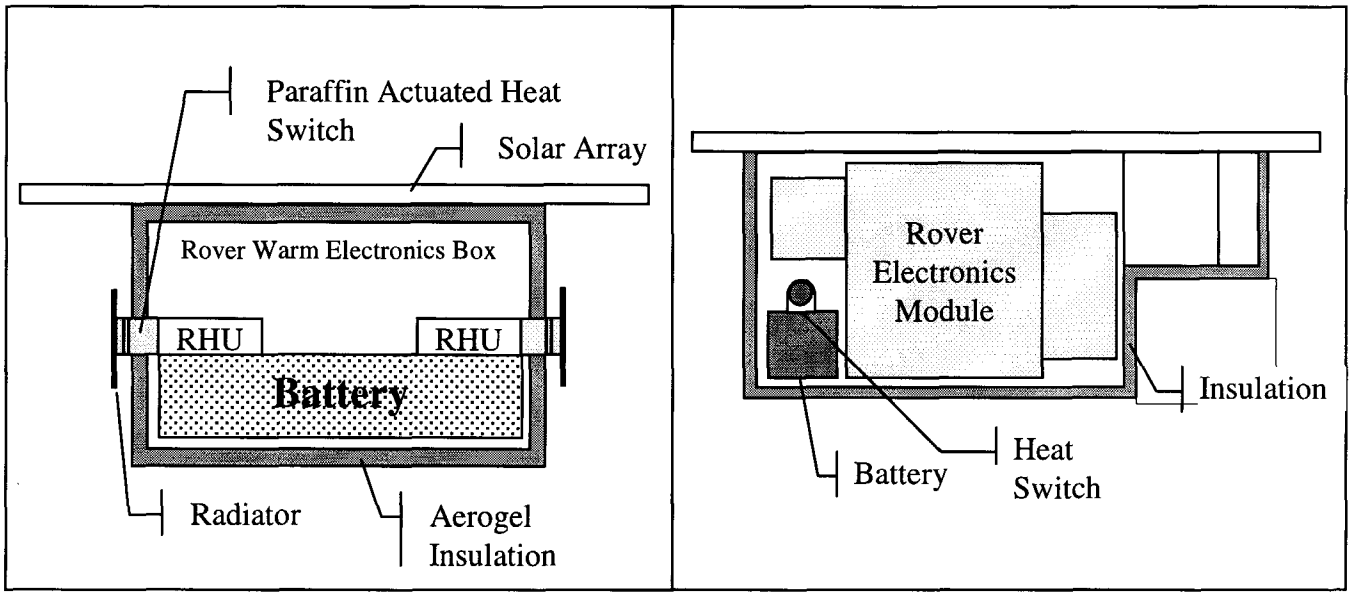
- The Heat Switch is a passive variable thermal conductance device
- Two aluminum cylinders are separated by a 1 mm gap when the switch is opened to minimize heat loss at cold conditions
- A pure single-chain paraffin with a melting point of 18°C actuates the switch



Description of the Heat Switch

•The Heat Switch removes excess heat from the Rover battery during daytime operations

•It provides thermal isolation for the battery from the cold night temperatures on Mars

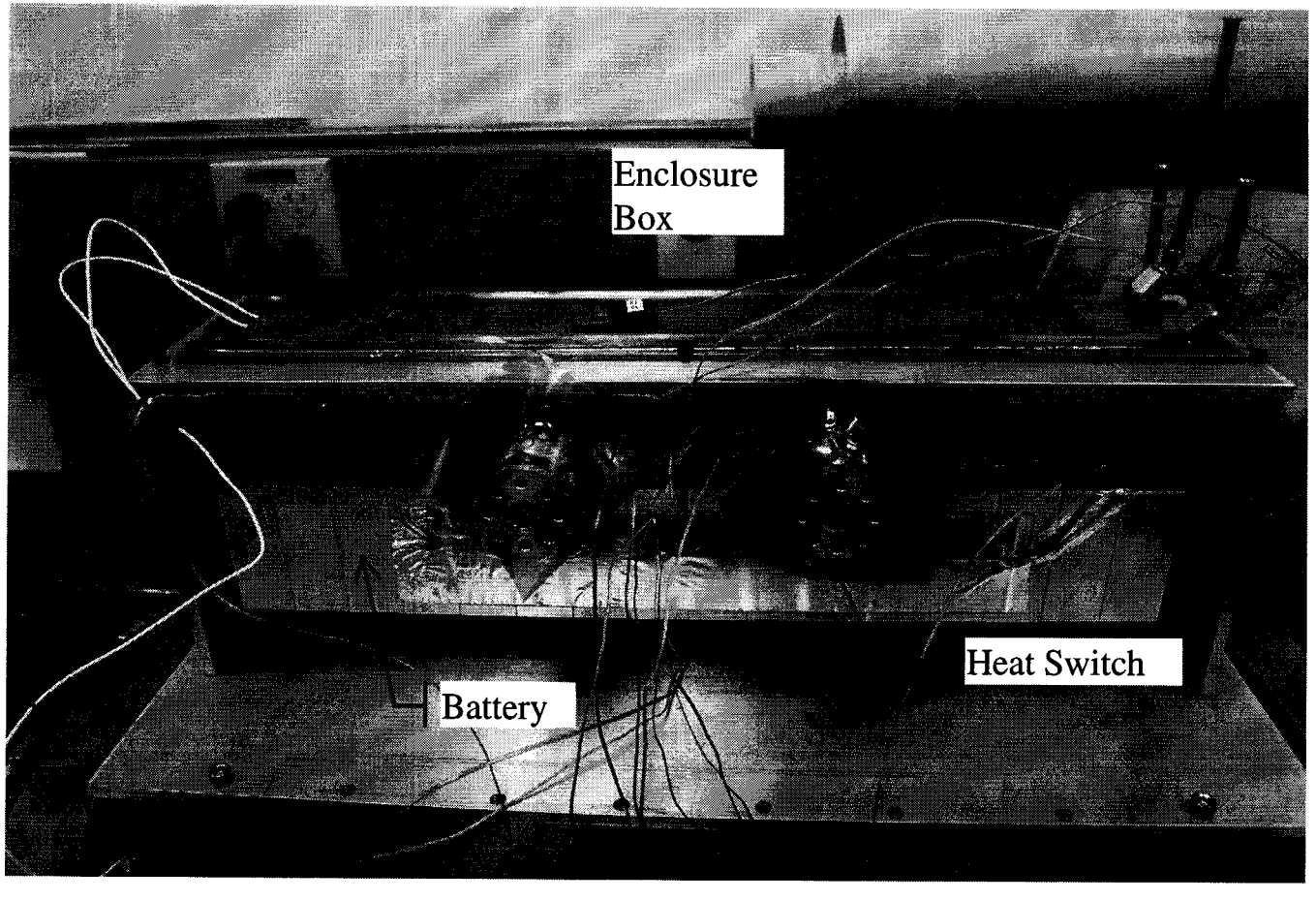


Schematic of Heat Switch Installation on Mars Rover

Development Test Program

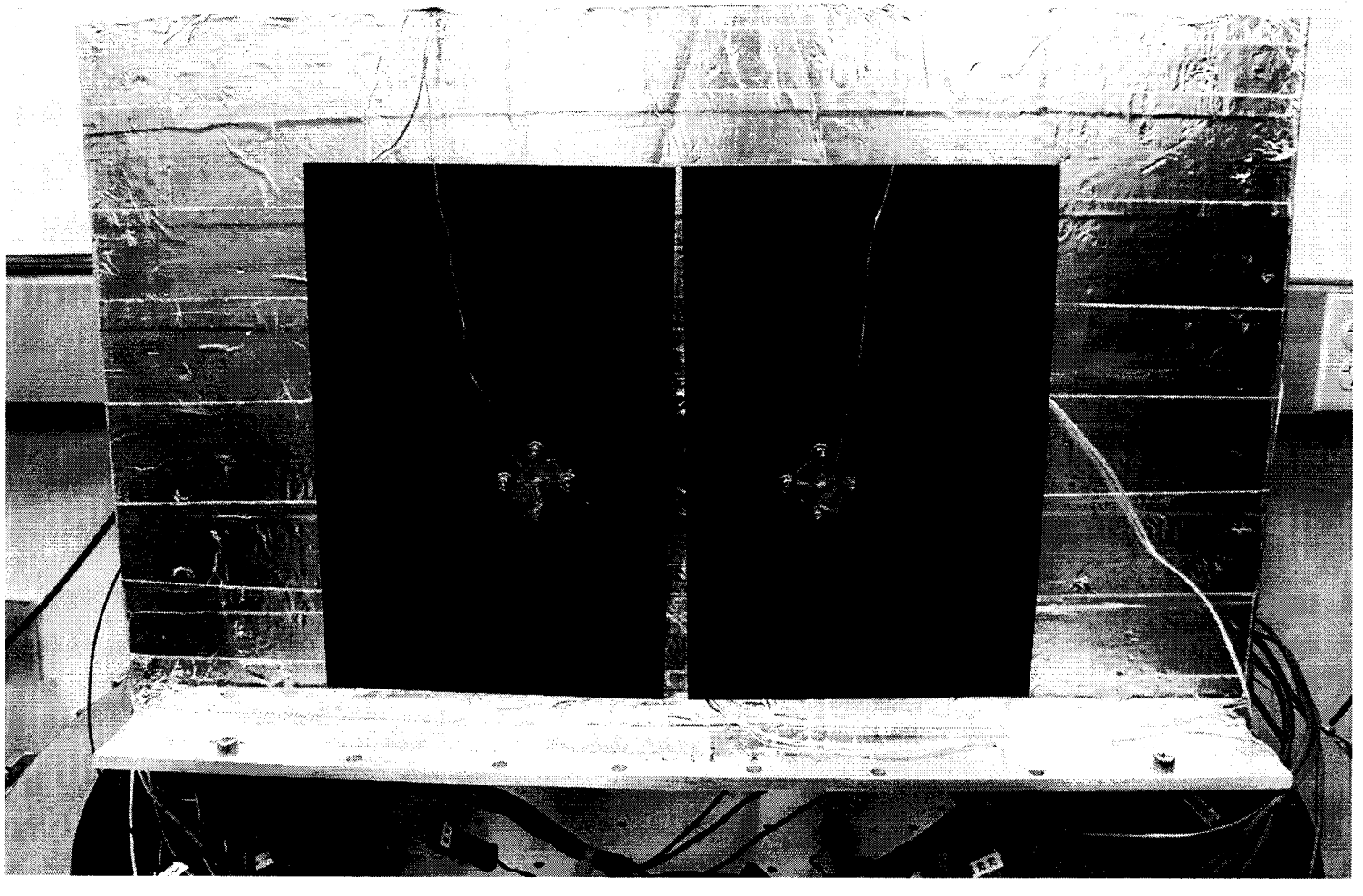
- The Heat Switch was subjected to the following tests during the development program:
- Measure thermal conductance across the switch over:
  - The operating temperature range of the battery
  - The expected Mars ambient environment at 8-10 Torr CO_2
- Characterize the switch performance over:
  - The hot case Mars diurnal cycle
  - The cold case Mars diurnal cycle
  - One switch failing open (only one operable switch)

JPL Heat Switch Test Facility



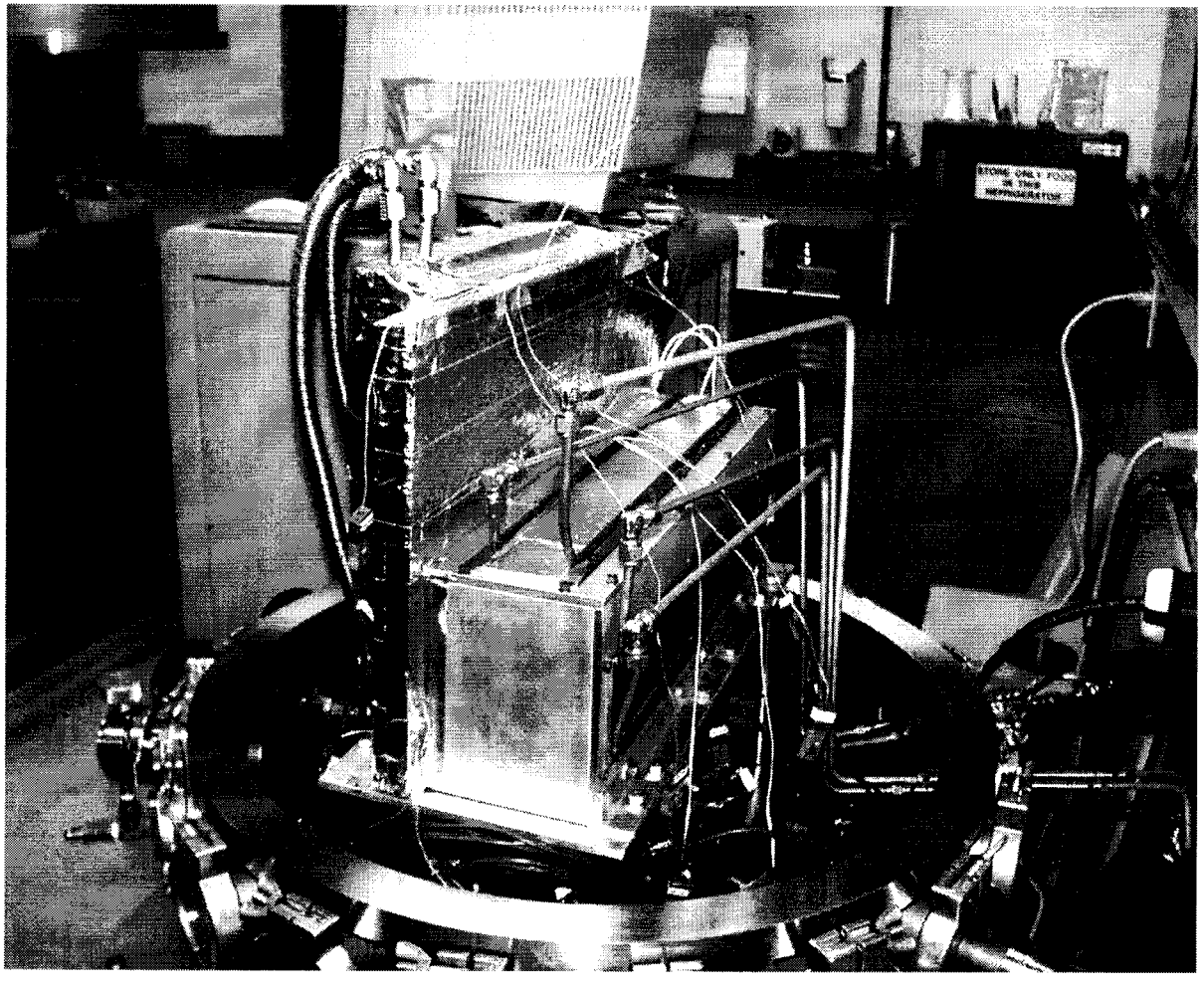
Two Heat Switches mounted to the mock battery assembly

JPL Heat Switch Test Facility



Heat Switch radiators mounted outside the insulated wall of battery box

JPL Heat Switch Test Facility

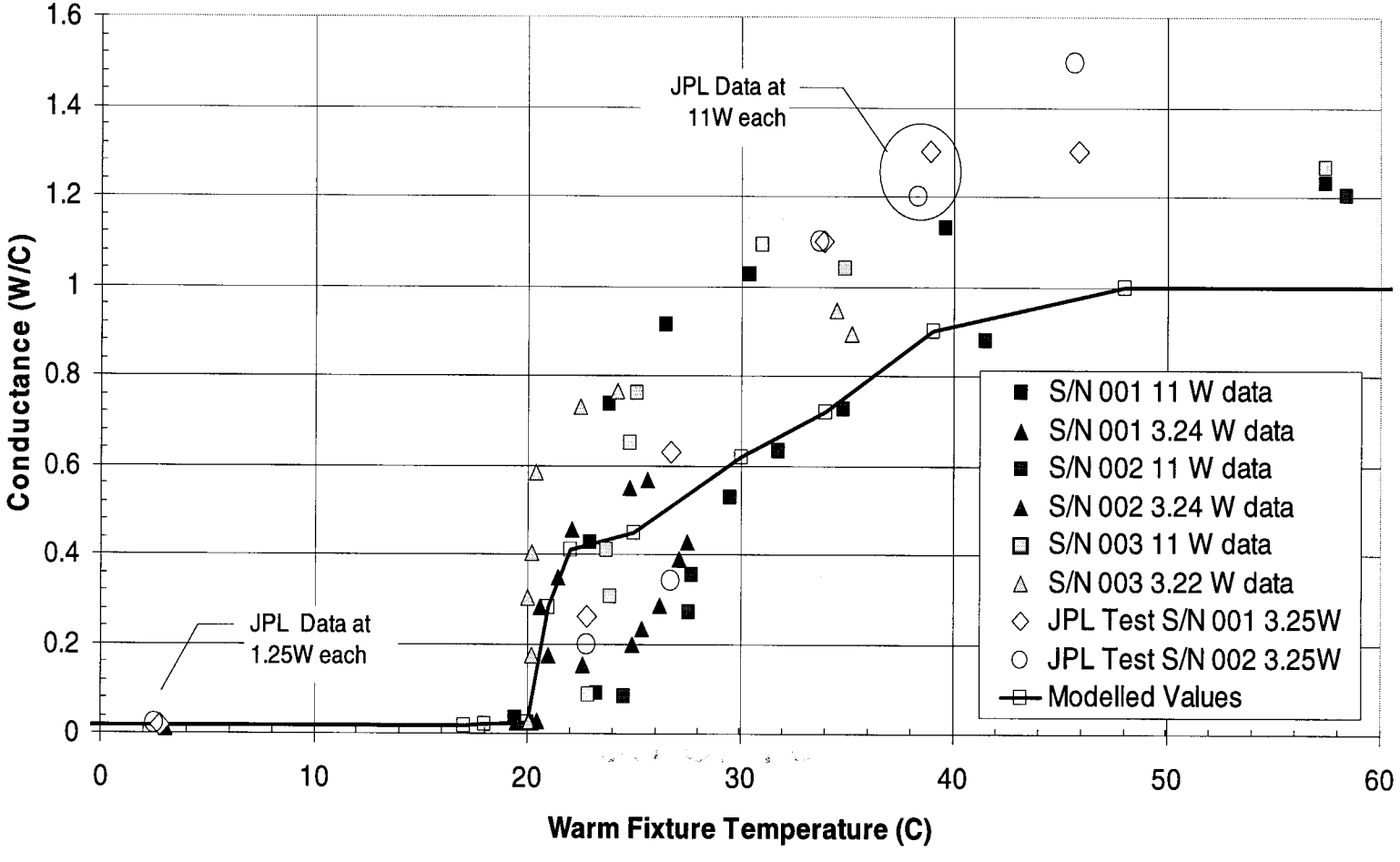


Complete Heat Switch test set-up in the vacuum chamber

Discussion of Test Results

- Thermal conductance measurement of the Heat Switch
  - Point design heat load was 3.25 watts per switch in closed conductance measurements: 0.6W/°C at 30°C on the warm side
    - Sink temperatures were set to 30, 15, 0 and -19°C
  - Open switch conductance measurement used a "heat leak" of 1.25 watts per switch: 0.019W/°C at 4°C on warm side.
    - Sink temperature was set to -80°C
  - High power closed switch conductance was made at 11 watts each: 1.2W/°C at 40°C

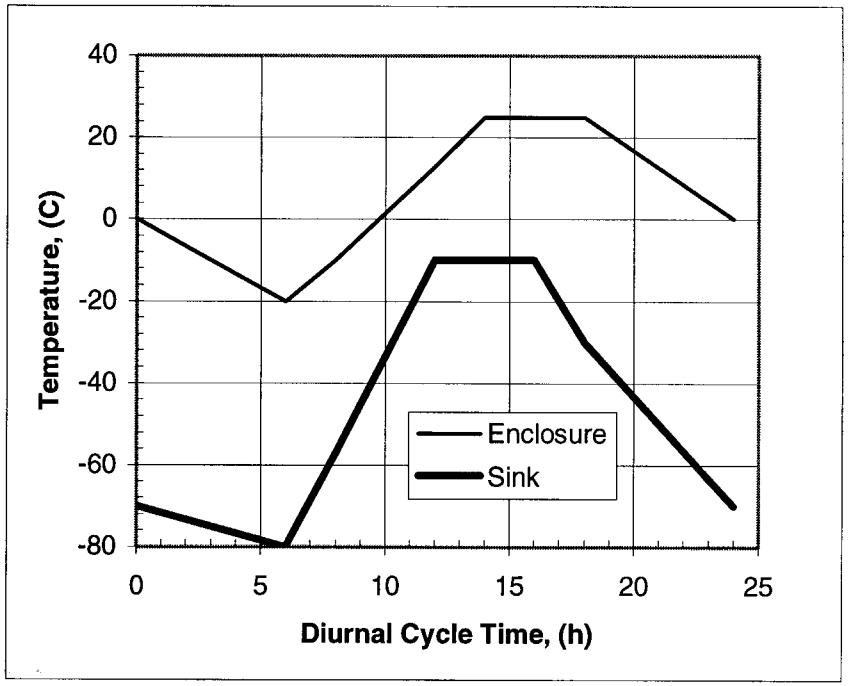
Discussion of Test Results



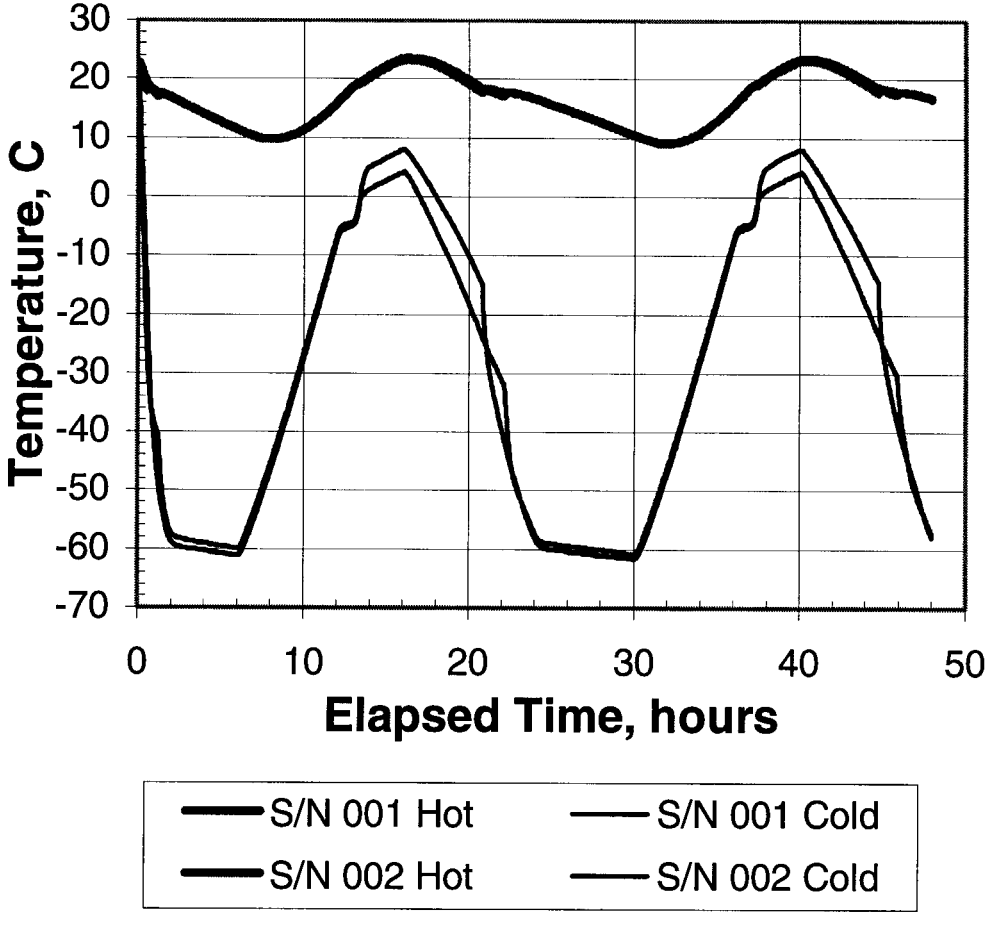
Heat Switch Conductance Values

Discussion of Test Results

- Mars Diurnal Cycle: Hot Case
  - Representative of Mars diurnal temperature profile at the beginning of the mission
  - Battery box tracks thermal model predictions for battery boundary conditions
  - Radiator box tracks model predictions for Mars ambient environment
  - Two consecutive cycles ran for 48 hours
  - 6.5 watt continuous load on battery with 1.5 watt parasitic load for 8 hours each day to simulate daytime operations.

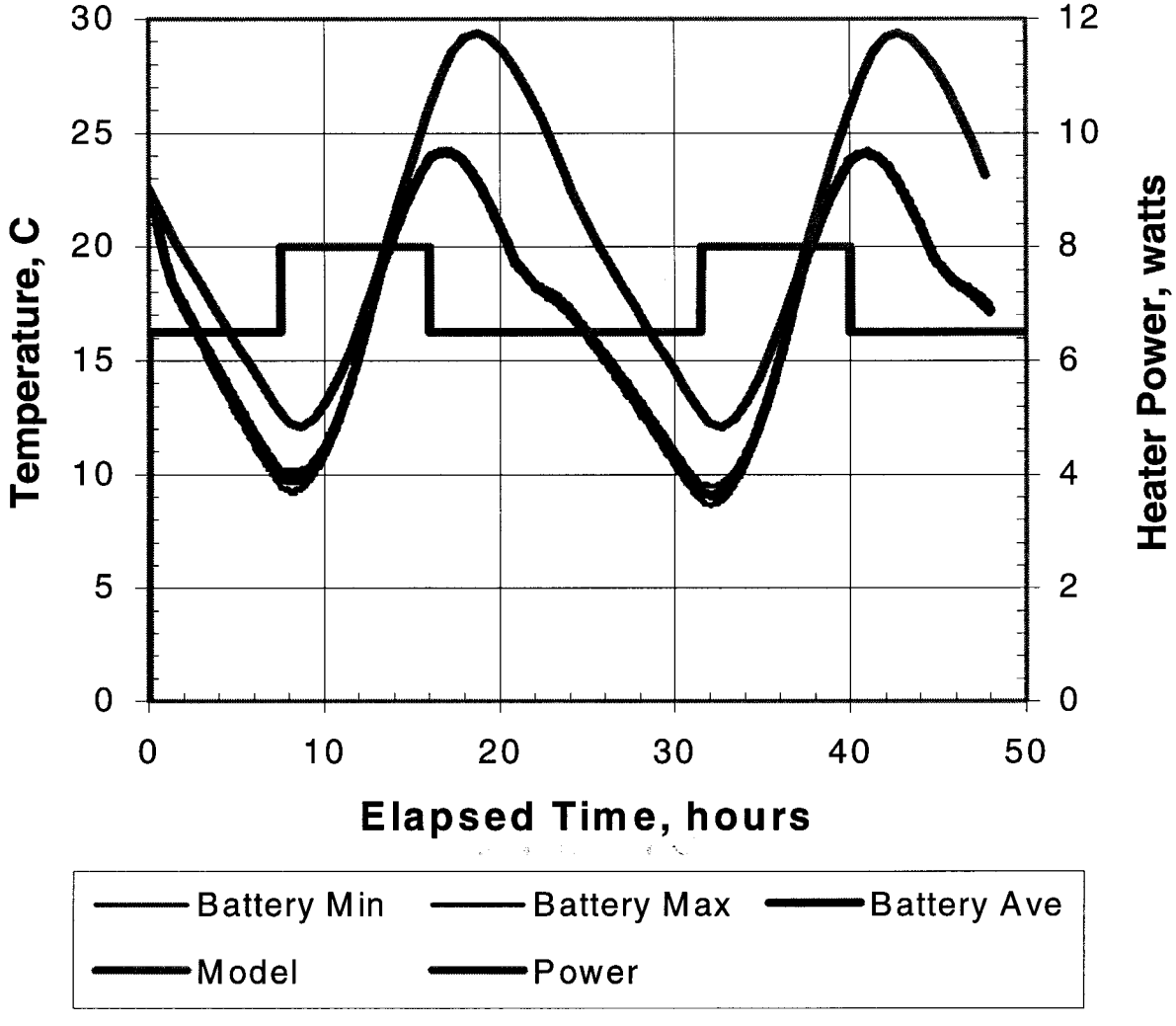


Discussion of Test Results



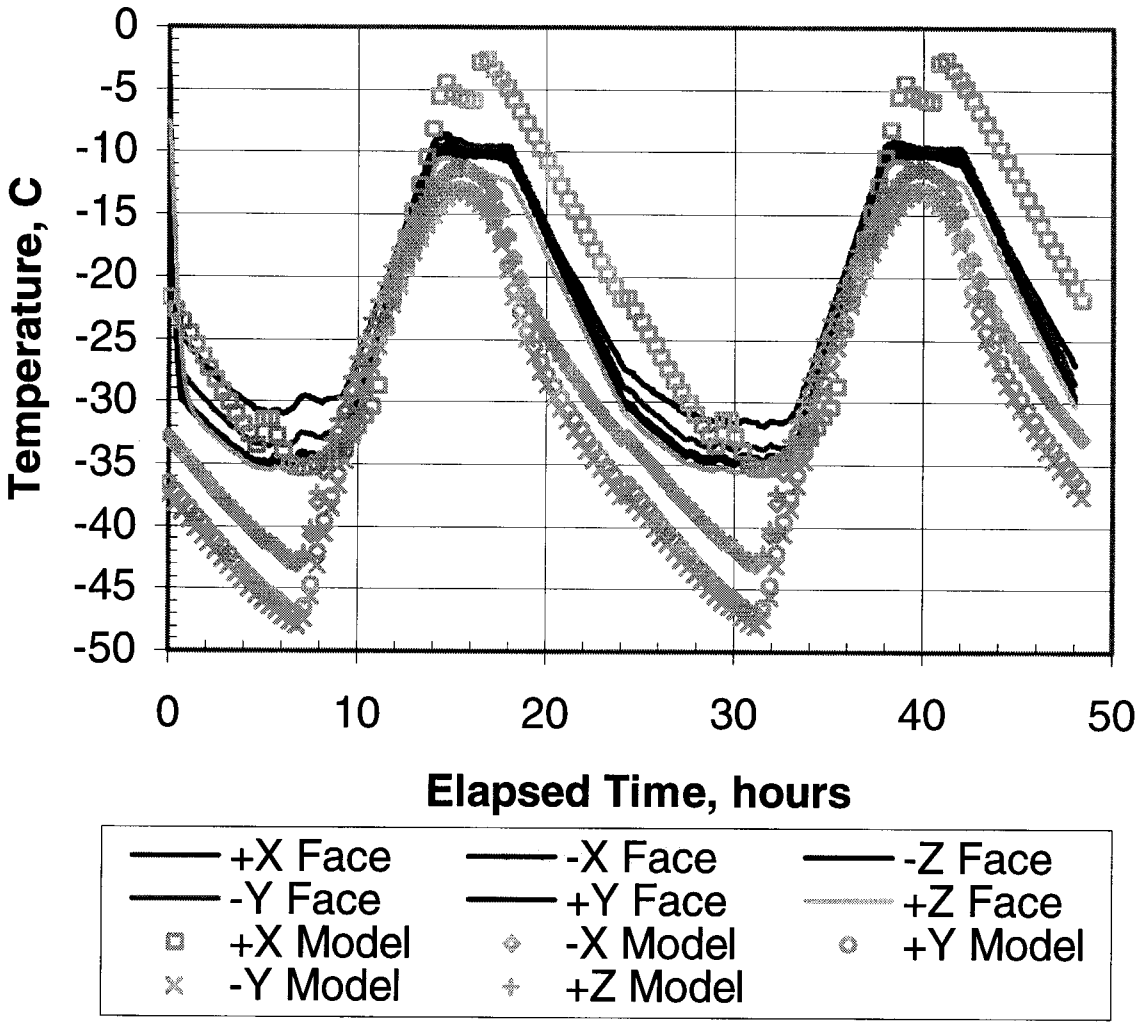
Heat Switch face temperatures during Hot Case Diurnal Cycle

Discussion of Test Results



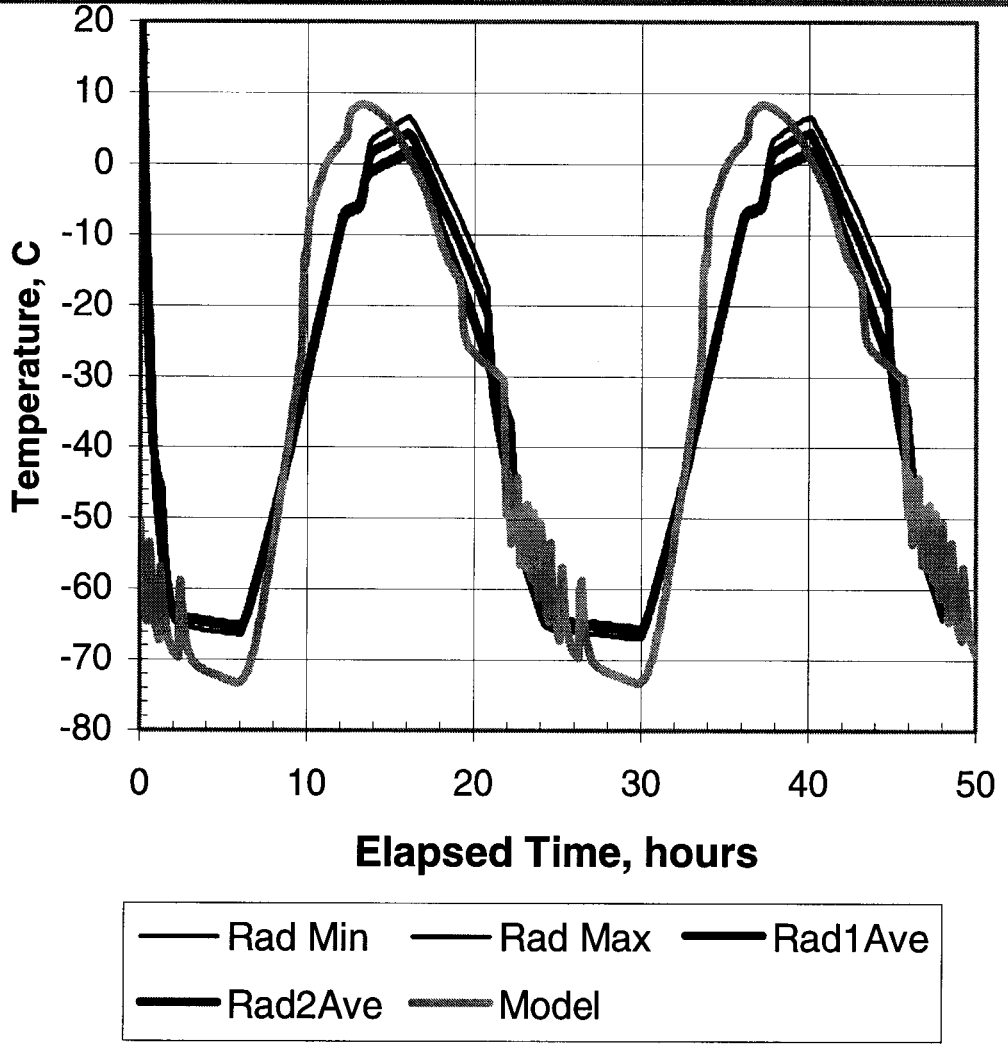
Battery temperature compared to model predictions for Hot Case

Discussion of Test Results



Battery enclosure temperature compared to model predictions for Hot Case

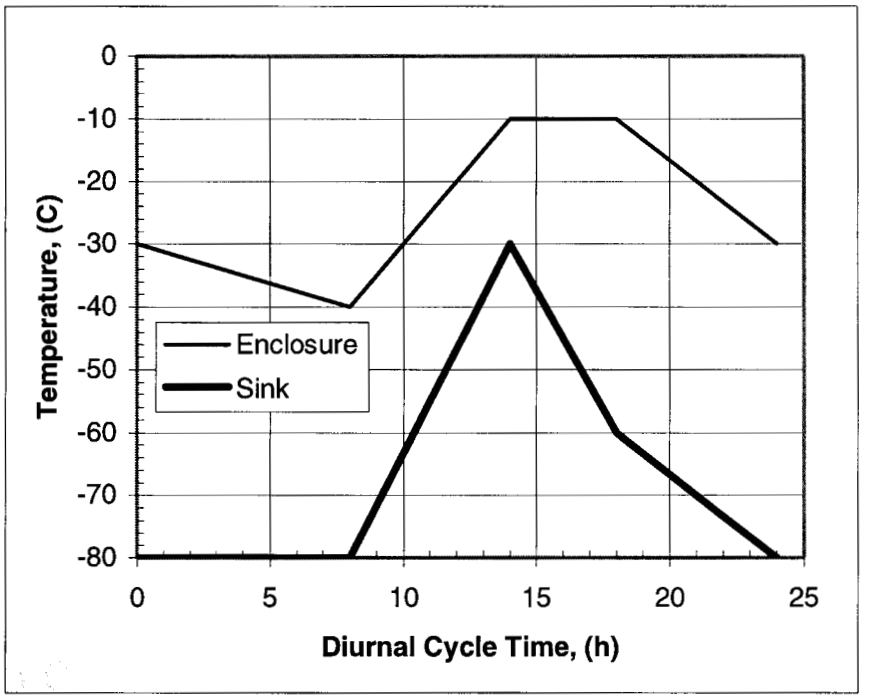
Discussion of Test Results



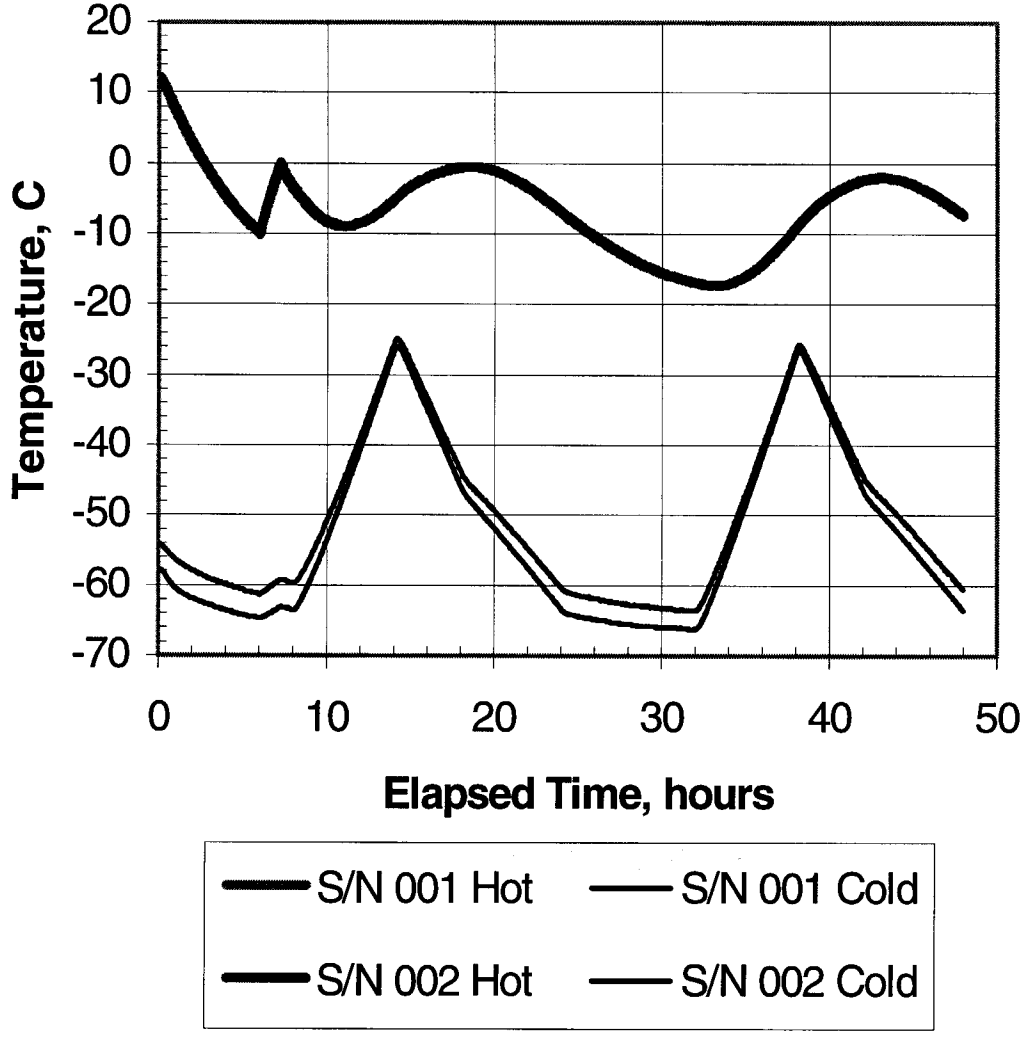
Radiator temperature compared to model predictions for Hot Case

Discussion of Test Results

- Mars Diurnal Cycle: Cold Case
  - Representative of Mars diurnal temperature profile at the end of the mission
  - Battery box tracks thermal model predictions for battery boundary conditions
  - Radiator box tracks (limited to –80C) model predictions for Mars ambient environment
  - Two consecutive cycles ran for 48 hours
  - 6.5 watt continuous load on battery with 20 watt warm-up load at 6th hour of the cycle

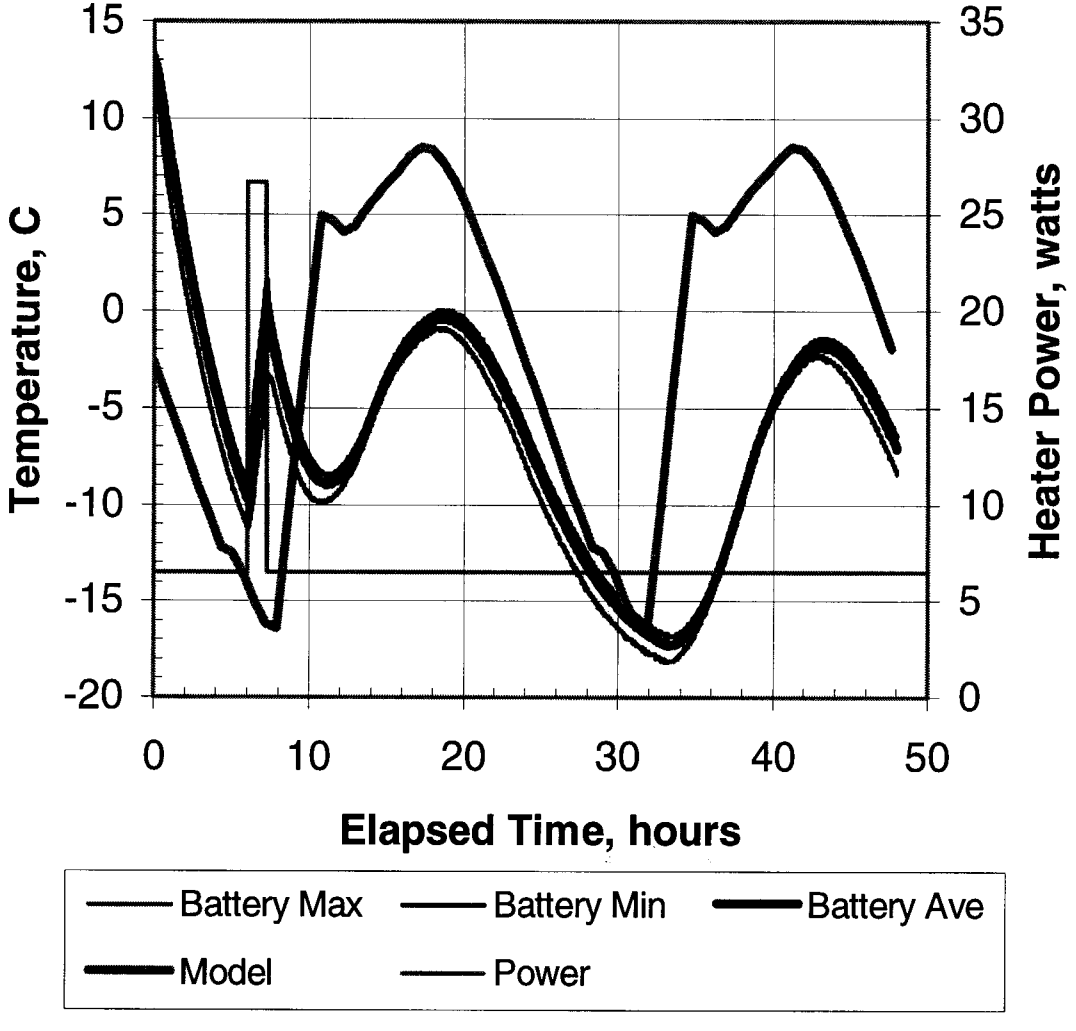


Discussion of Test Results



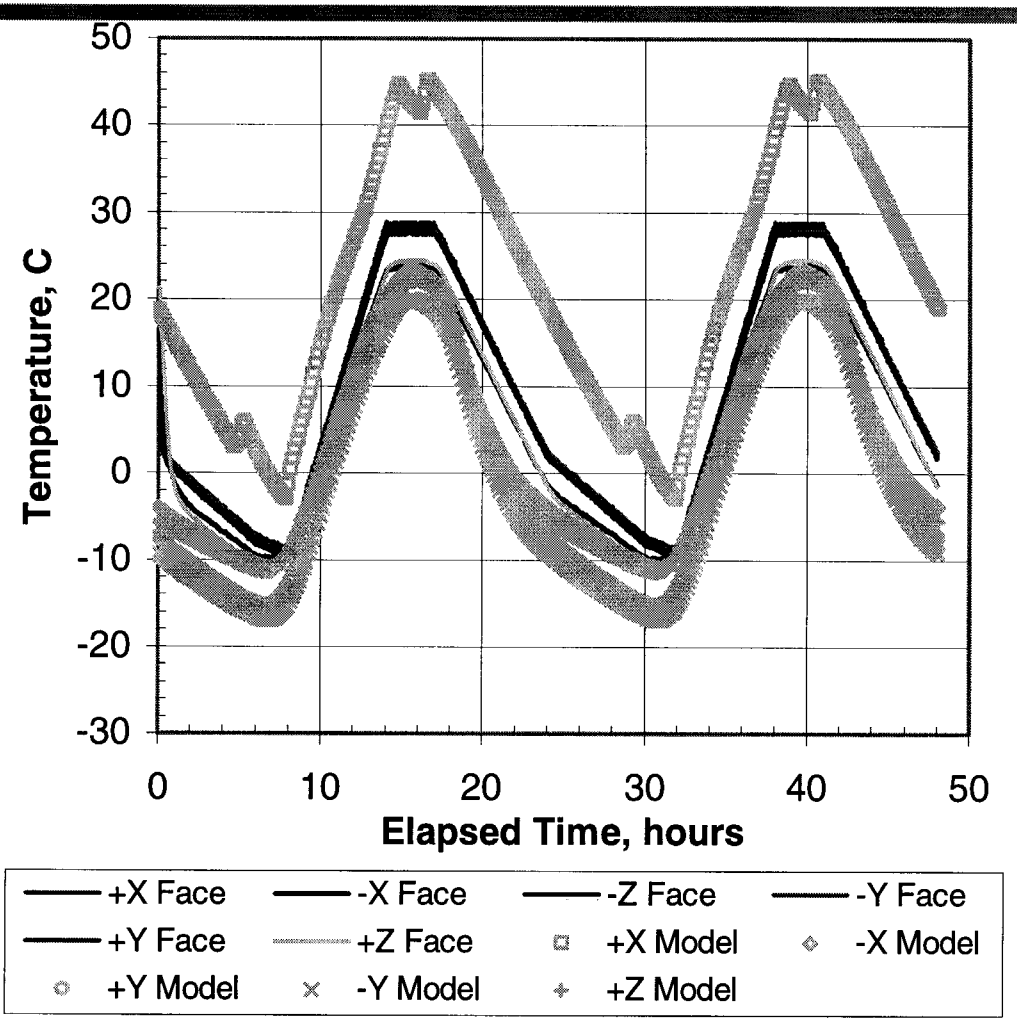
Heat Switch face temperatures during Cold Case Diurnal Cycle

Discussion of Test Results



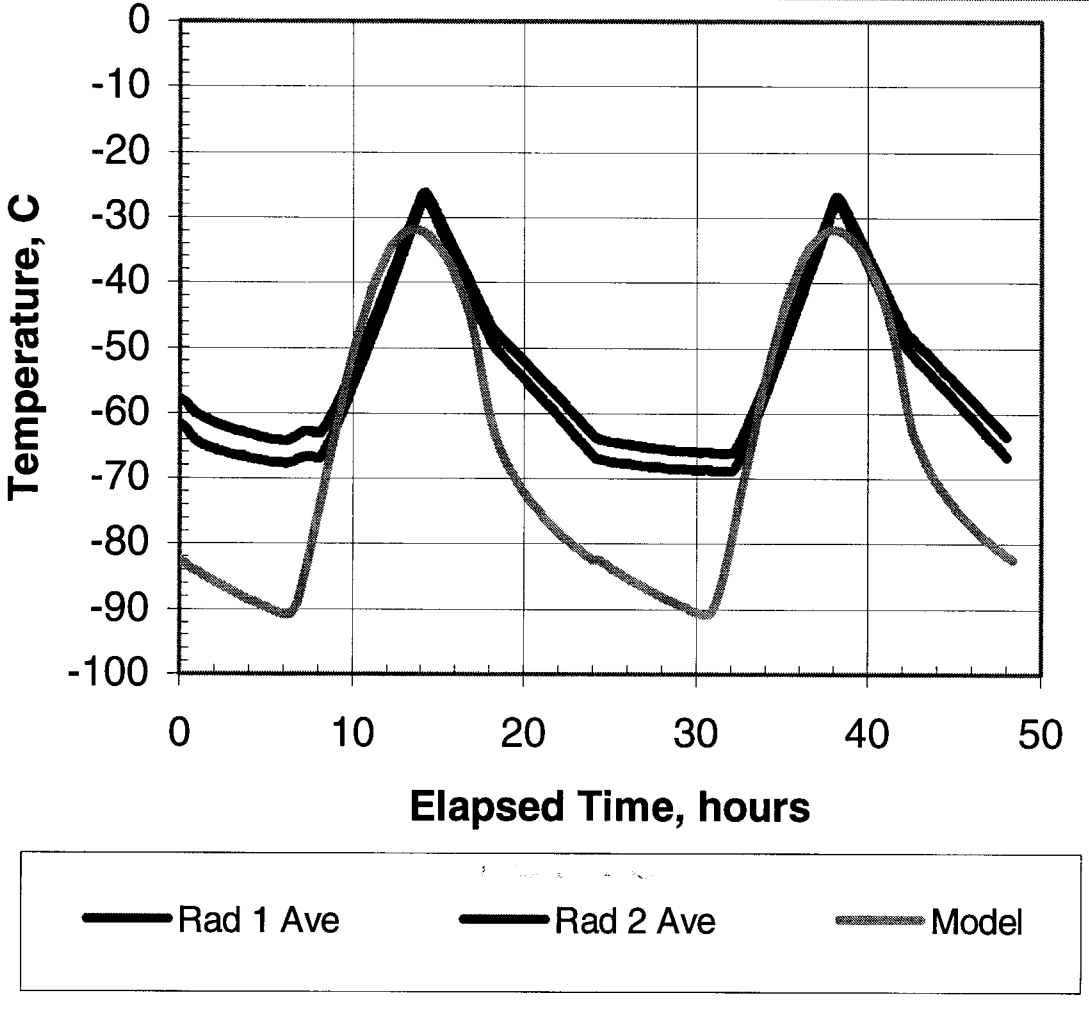
Battery temperature compared to model predictions for Cold Case

Discussion of Test Results



Battery enclosure temperature compared to model predictions for Cold Case

Discussion of Test Results

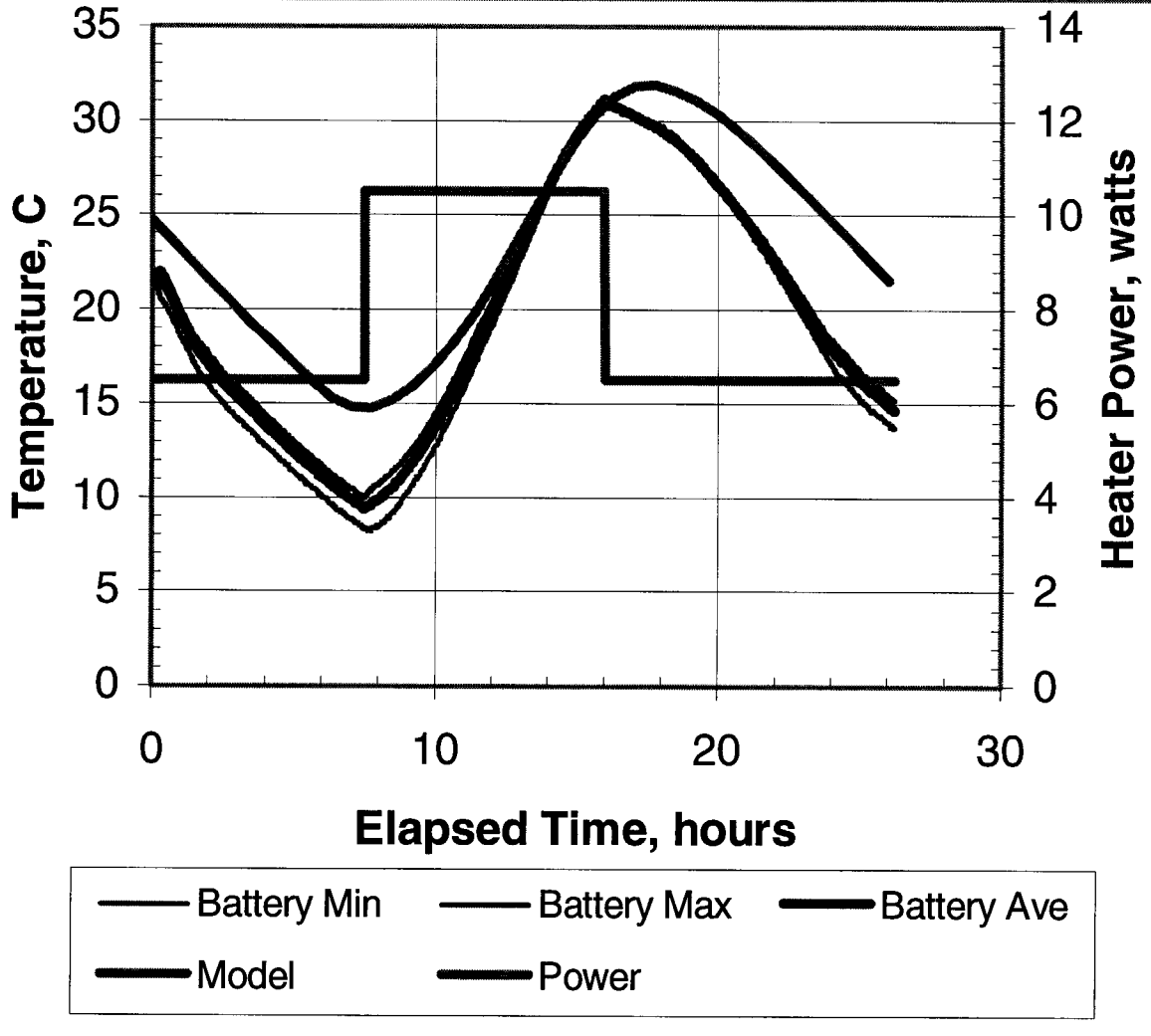


Radiator temperature compared to model predictions for Cold Case

Discussion of Test Results

- One switch failed open test
  - An open switch is the most probable mode of failure
  - Simulated by removing the radiator of one switch
  - Ran the Hot Case diurnal cycle for 24 hours
- The maximum battery temperature was 32°C
  - Only 2°C above AFT for the battery but not deemed catastrophic

Discussion of Test Results



Battery temperature compared to model prediction for single switch failure

Conclusions

- The Paraffin-Actuated Heat Switch met the following requirements:
  - The thermal conductance of the heat switch when open was 1/30 of the closed conductance value
  - Maintained the battery well below the maximum AFT in the hot case
  - Indicates that a minimal amount of electric heat will be required to maintain the battery above the minimum AFT in the cold case
  - A single switch failure in the open position is not catastrophic for the battery