14th Spacecraft Thermal Control Technology Workshop

Thermal Hardware Lessons Learned & Preliminary System Level Test Results for the Mars Exploration Rover

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March 13, 2003

Agenda

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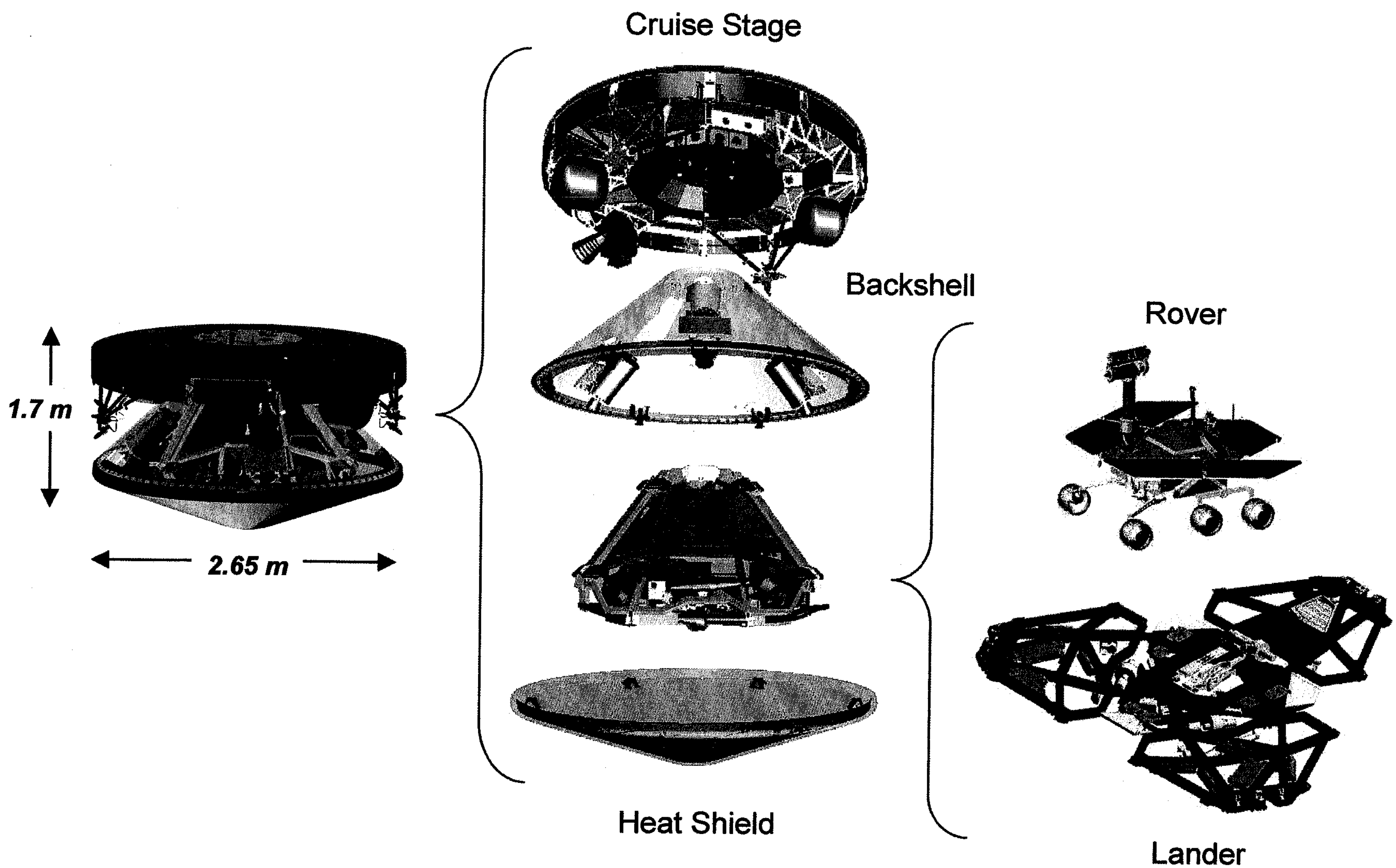
- Spacecraft Configuration
- Major Lessons Learned for Hardware
  - IPA Accumulator Overpressurization
  - IPA Motor Controller Thermal Vacuum Test Failure
  - Cruise Shunt Radiator Heater Adhesion
  - Rover Shunt Radiator Heater Adhesion
- Preliminary System Thermal Test Results
  - Dual Flight System Test Approach
  - Cruise Solar/Thermal Vacuum Test
  - Rover Martian Thermal Test
- Epilogue

MER Project Description

- The Mars Exploration Rover (MER) is a mission to land two identical roving science vehicles on Mars and perform geological science data collection with a surface science 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 Jan 2004, deploy the rovers and conduct surface operations.
  - MER - A is the first launched (May - June 2003), first arriving (early Jan. 2004) flight system.
  - MER - B is the second launched (June - July 2003), second arriving (late Jan. 2004) flight system.
- Each Flight System consists of:
  - A cruise stage and entry, descent and landing system (EDL) with inheritance from the Mars Pathfinder (MPF) development
  - A rover based upon the Athena Rover developments undertaken for the Mars '01 and Mars Sample Return projects (1 km traverse capability)
  - Athena Science Package, 5 science instruments to conduct remote and in-situ observations

MER Spacecraft Configuration

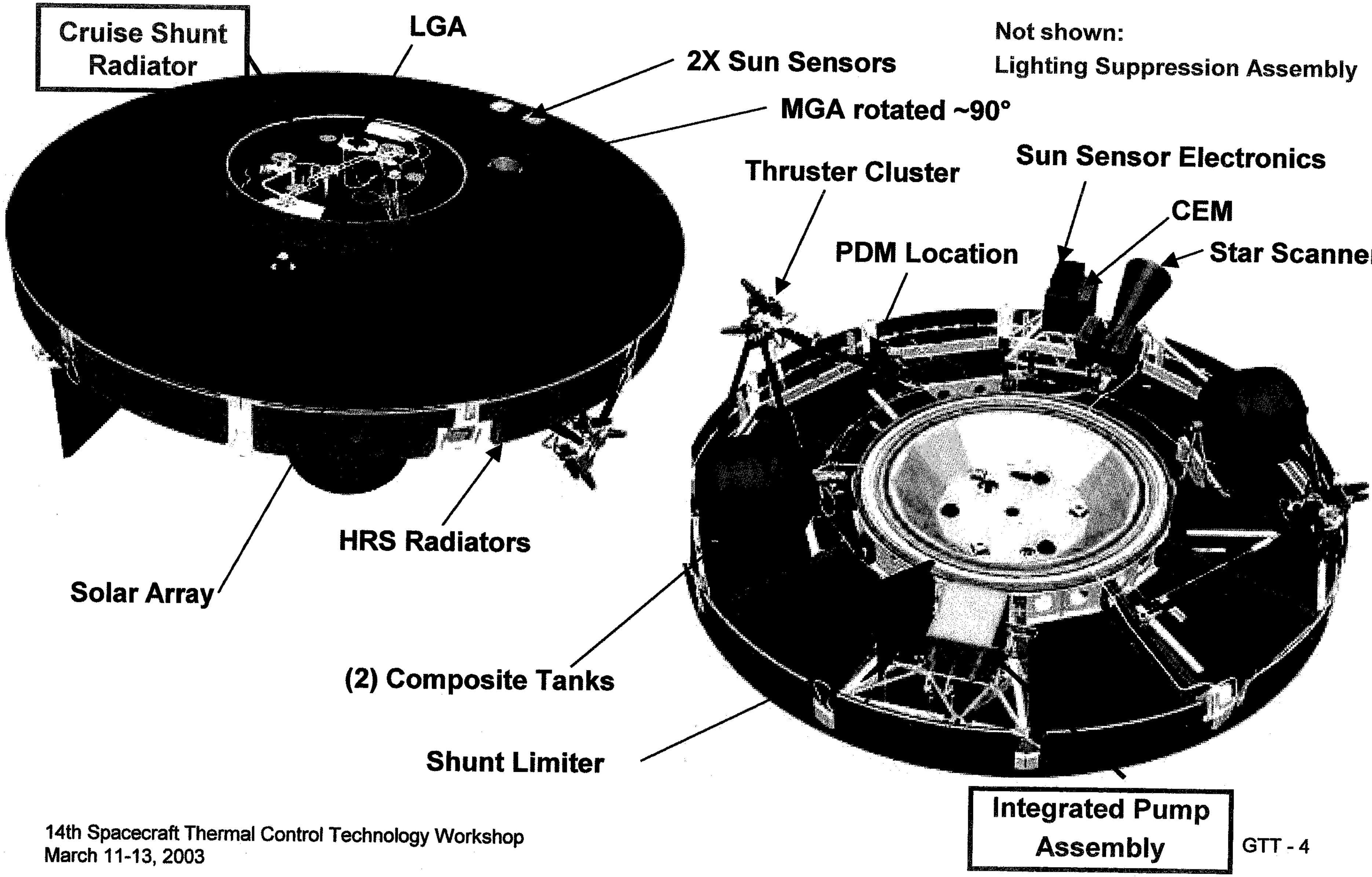
Mars Exploration Rover



Cruise Stage Configuration

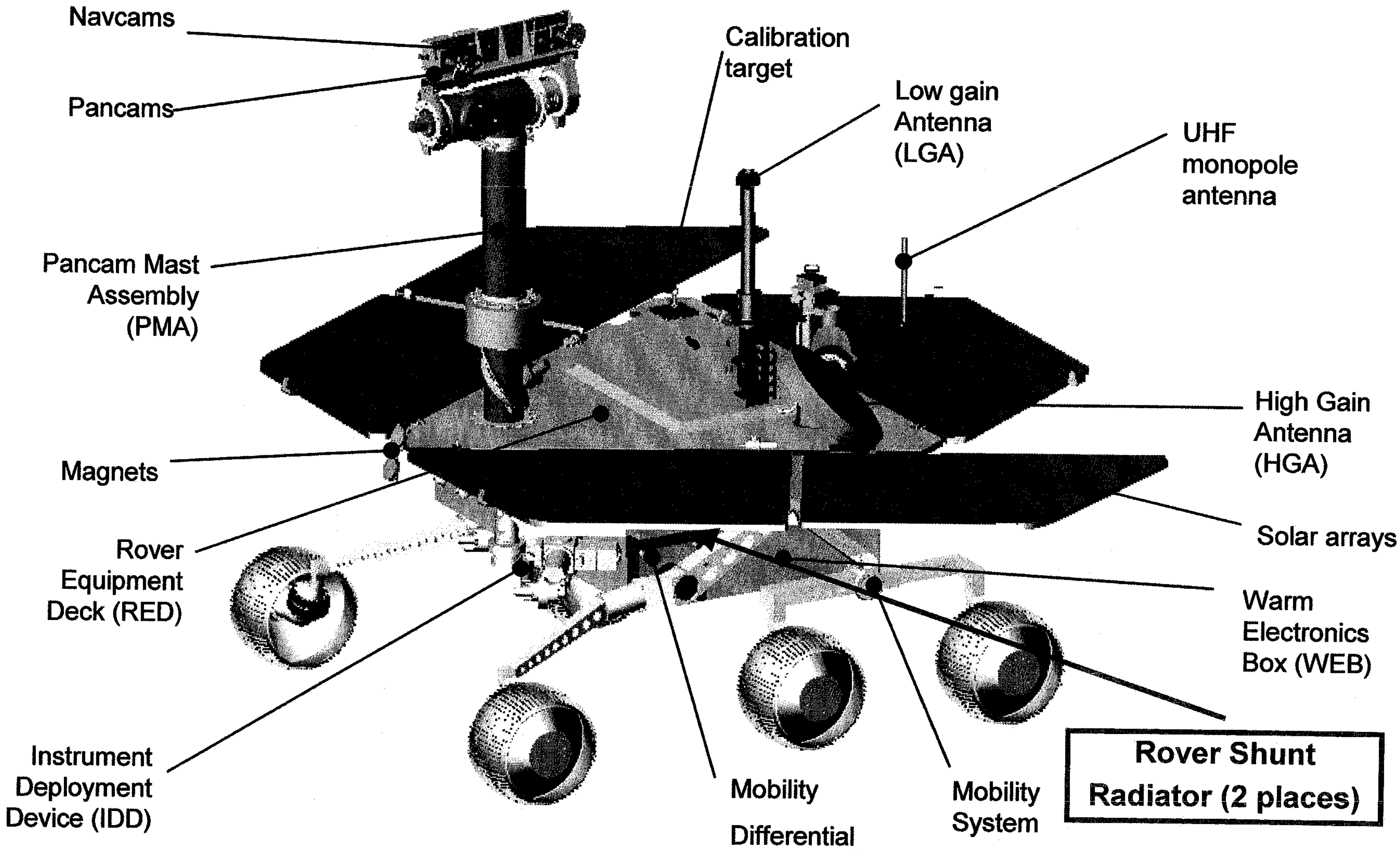
Mars Exploration Rover

Not shown:
Lighting Suppression Assembly



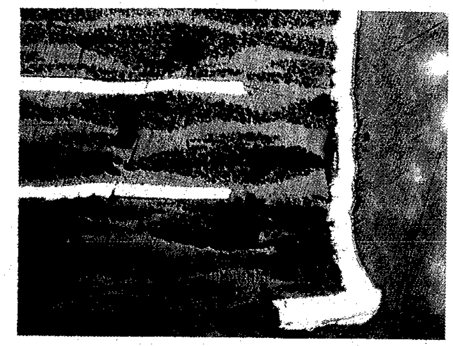
Rover Configuration - Deployed

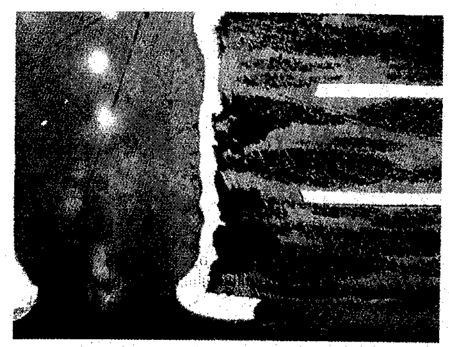
Mars Exploration Rover

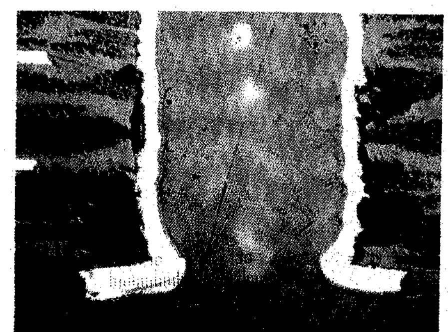


IPA Motor Controller

- **Motor controller electronics underwent PF thermal vacuum testing February 2002**
  - 144 hours at +70°C
  - Significant drop in current draw detected after 72 hours
- **A number of soft shorts found between discrete components**
  - MPF IPA subcontractor used MPF artwork without Gerber files
  - Circuit board workmanship suspected
- **Destructive analysis performed**
  - Layers significantly misregistered
  - Vias bored with a dull bit => creates sneak path for plating process
- **Circuit boards refabricated by another vendor**
  - Integra-testing successfully performed
- **PF thermal vacuum retest successful**



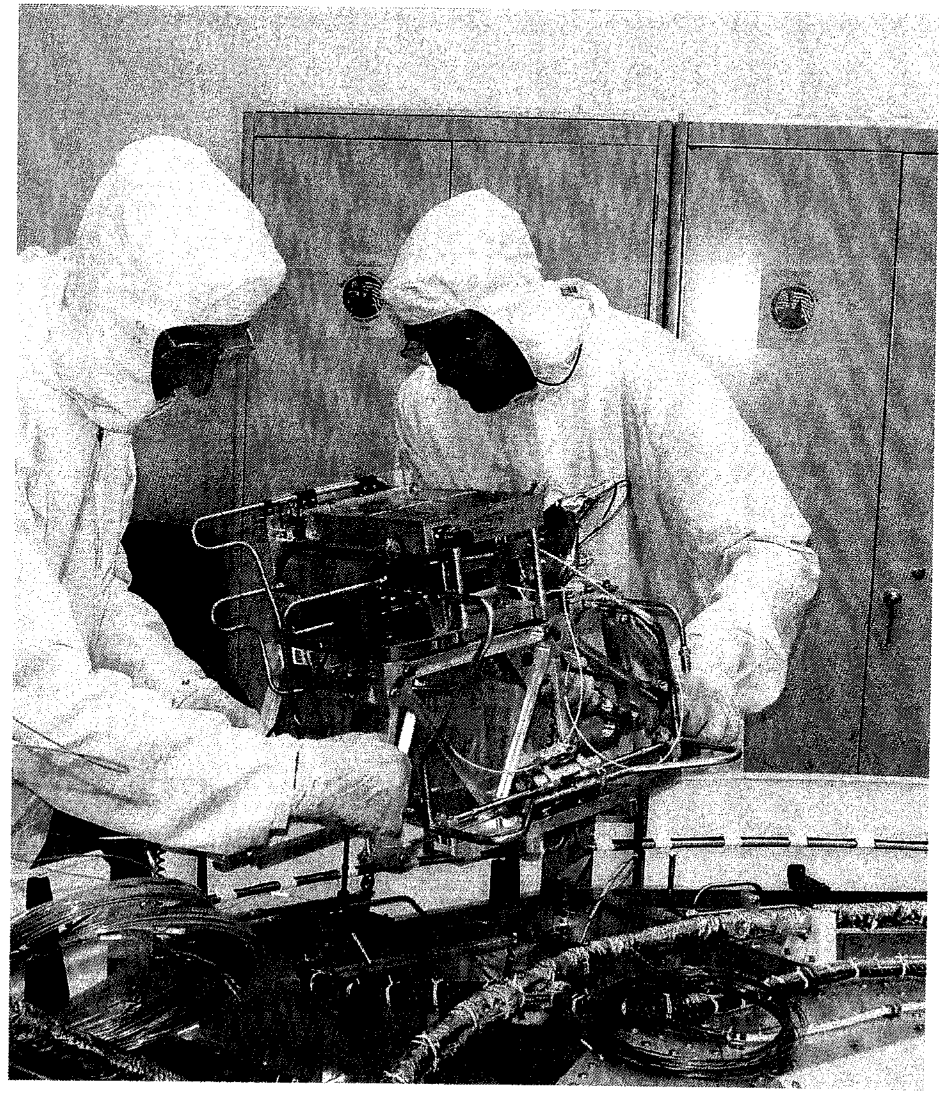




IPA Accumulator

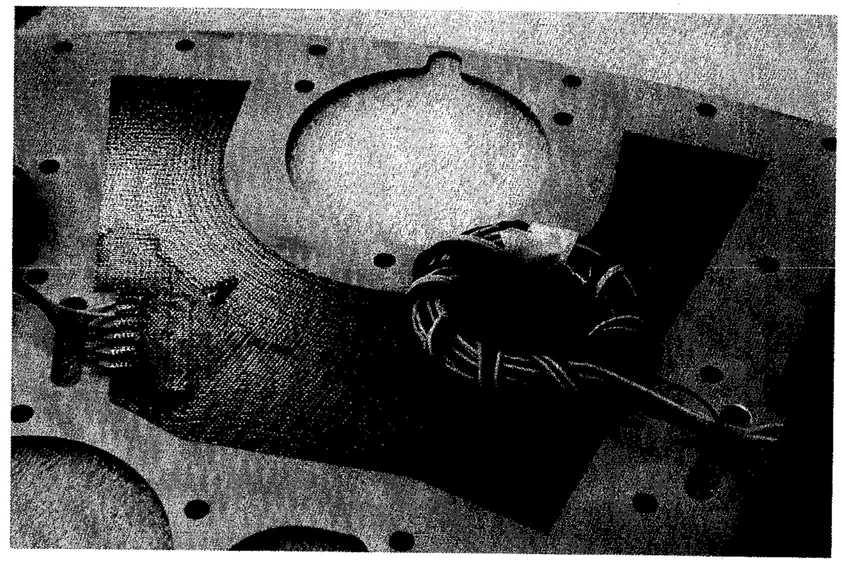
Mars Exploration Rover

- **1st flight IPA delivered to JPL in June 2002**
- **JPL conducted initial unit leak check in July 2002**
  - Accumulator gas side was allowed to leak to ambient
  - Accumulator liquid side was charged with Helium to 20 psig
  - Pressure differential across gas/liquid sides was 20 psid
  - Max design ΔP = 10 psid
- **Subsequent accumulator leak testing suggested bellows damage**
- **JPL decided to replace accumulator rather than fix bellows**
- **Repaired unit delivered 3 months later**



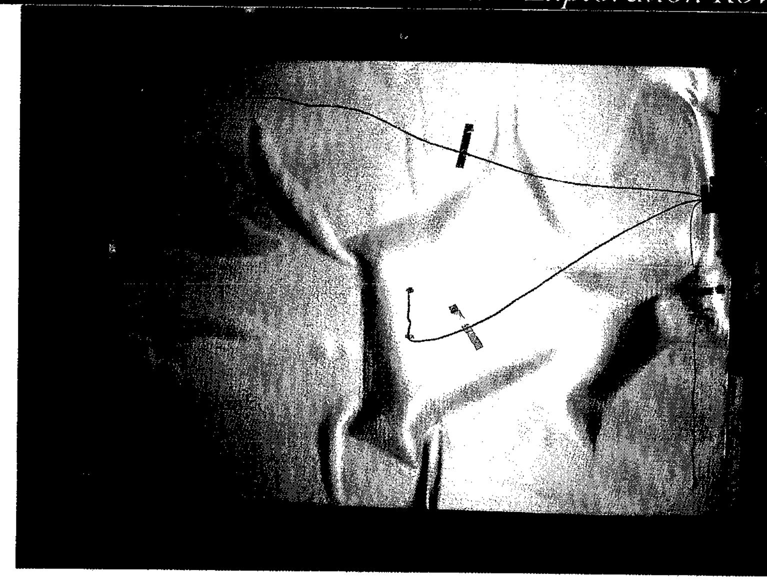
Cruise Shunt Radiator Heater Adhesion

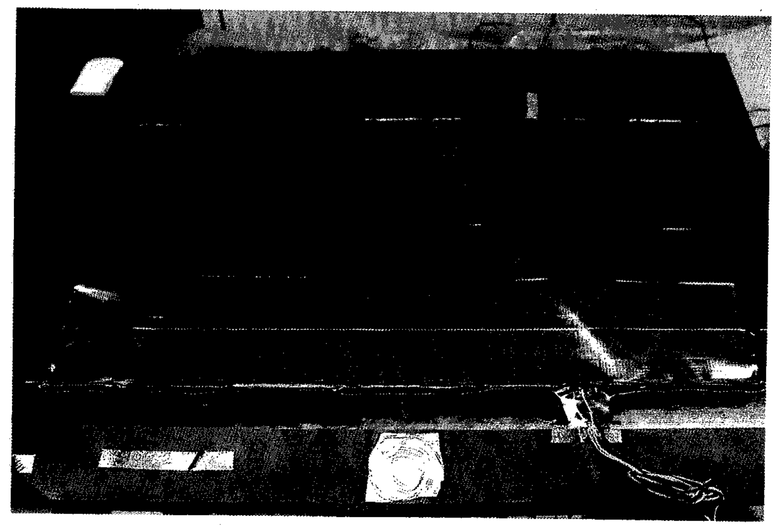
- **Initial approach used Kapton-film heater with Y966 adhesive on Magnesium alloy with Dow 23 surface finish**
  - QUAL thermal cycle testing between –55 to 120°C unsuccessful (top photo)
- **Successful adhesion required stripping of Dow 23, priming with BR-127, & applying heater with FM300 adhesive**
  - Vacuum-bagging to cure FM300
  - Failure to vacuum-bag thin plate against a tool resulted in plastic structural deformation (bottom photo)
- **Successful application resulted after vacuum-bag tool was used**



Rover Shunt Heater Adhesion

- **Solar cell vendor performed QUAL thermal cycling (-125 to 110°C) on flight-like Rover solar array coupon**
  - Significant heater blistering & some edge delamination (top photo)
  - Problem traced to CTE mismatch between aluminum heat sink for heater & carbon composite array substrate
- **Second coupon fabricated**
  - Epoxy adhesive along heater edges
  - AgFEP tape overlay replaced by Kapton tape
  - 180 of 270 thermal cycles between -110 & 90°C complete with minimal bubble population & height (bottom photo)





Dual Flight System Thermal Test (STT) Approach

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- Verify single cruise & landed thermal design
  - MER-1 cruise stage empirically
  - MER-2 Rover on basepetal via test-correlated analytical models
    - Extremely difficult to faithfully represent worst-case diurnal Martian environment under test conditions
    - Rover equipment deck with external appendages exposed to Martian solar flux in a separate system thermal test

- Validate cruise & landed thermal design on remaining flight system elements
  - MER-1 Rover on basepetal
  - MER-2 cruise stage
  - MER-2 Rover equipment deck solar exposure
  - Test case matrix typically is a smaller subset of design verification testing

MER-1 Cruise STT : Test Article

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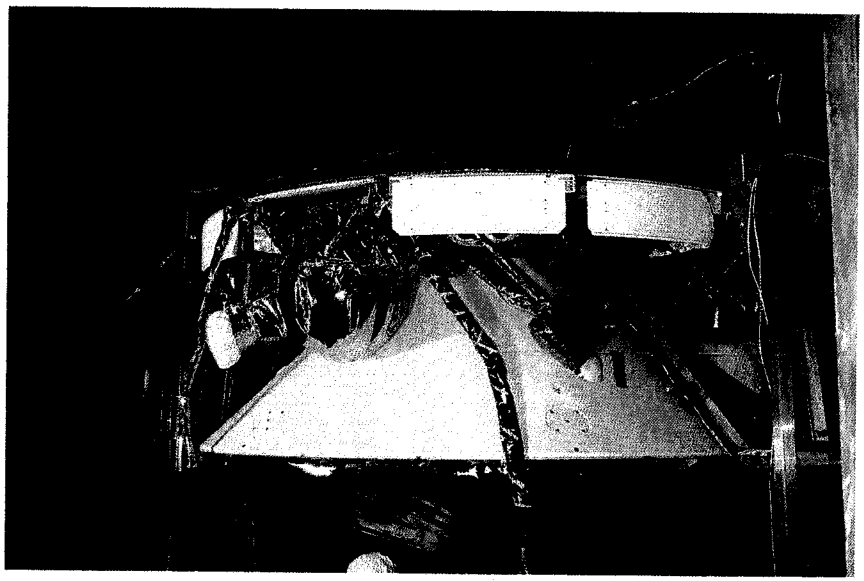
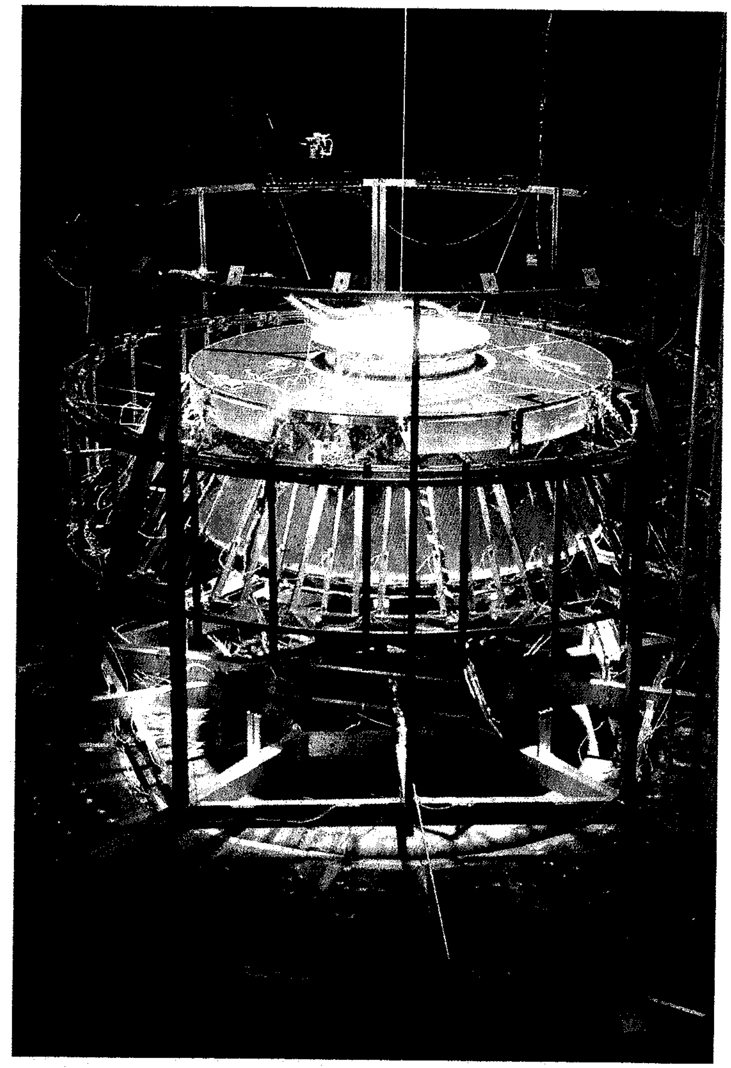
- **Test Article Integrated in Chamber**





MER-1 Cruise STT: Thermal Design Margins

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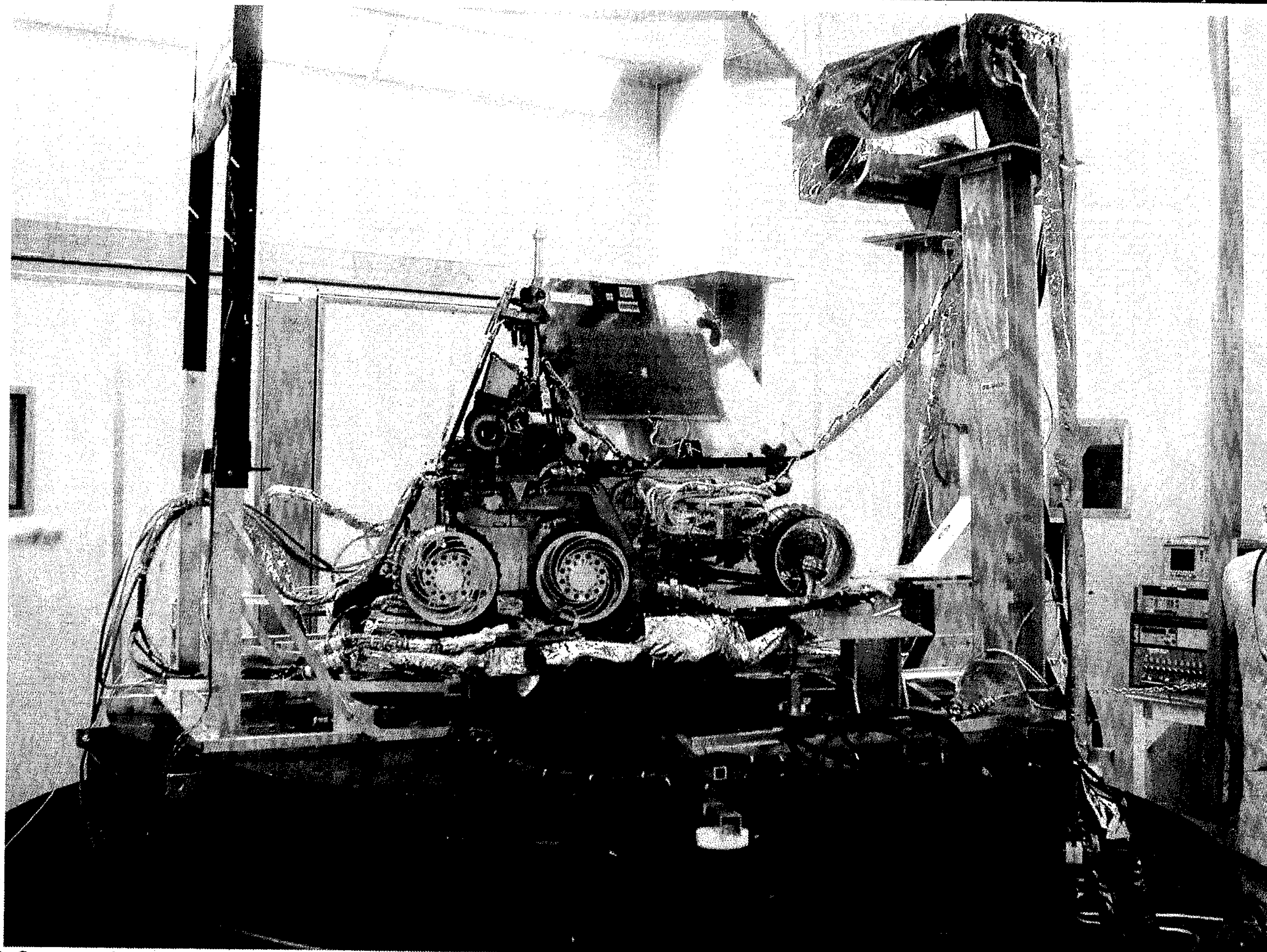
- **Hot Case margins**
  - Cruise stage h/w has large margins for nominal & fault S/C attitudes (generally > 20°C). Exceptions include propulsion distribution module (–7°C) and solar panels (2°C) during fault attitudes.
  - Lander hardware has large margins for nominal & fault S/C attitudes (generally > 20°C)
  - Rover battery has adequate margins for nominal (7°C) & fault (5°C) S/C attitudes
  - Rover electronics module hot/cold sides have 31°C ±3°C margin near earth

- **Cold Case margins**
  - Cruise stage h/w has large margins for nominal & fault S/C attitudes (generally > 20°C)
  - Transverse impulse rocket system has only a 5°C margin during fault S/C attitude
  - Lander hardware has large margins for nominal & fault S/C attitudes (generally > 10°C)
    - Radar altimeter has 4°C margin during fault attitude.
  - Rover battery has adequate margins (8°C) for nominal & fault S/C attitudes
  - Rover electronics module hot/cold sides have 42°C ±3°C margin near Mars

MER-1 Cruise STT Notable Anomalies

- A number of thermostatically controlled heater circuits were swapped
  - "A" heater circuit controlling on "B" circuit thermostat setpoints
  - Rocket-assisted descent motor & thermal battery "A" & "B" thermostats were mis-wired
  - Backshell pyro switching assembly "A" & "B" thermostats were incorrectly installed
  - Rover battery warm-up & survival heaters were incorrectly cabled so that warm-up acted as a survival & vice-versa
  - Propellant distribution module "A" & "B" thermostats were incorrectly installed or incorrectly wired
  - All thermostats except propellant distribution module were corrected
    - Propellant distribution module thermostats will fly "as-is," since there is no change in functionality => both "A" & "B" heater circuits are enabled in flight

MER-2 Rover Surface STT: Test Article In Stowed Position



MER-2 Rover Surface STT: Test Article After Stand-up & Deployments

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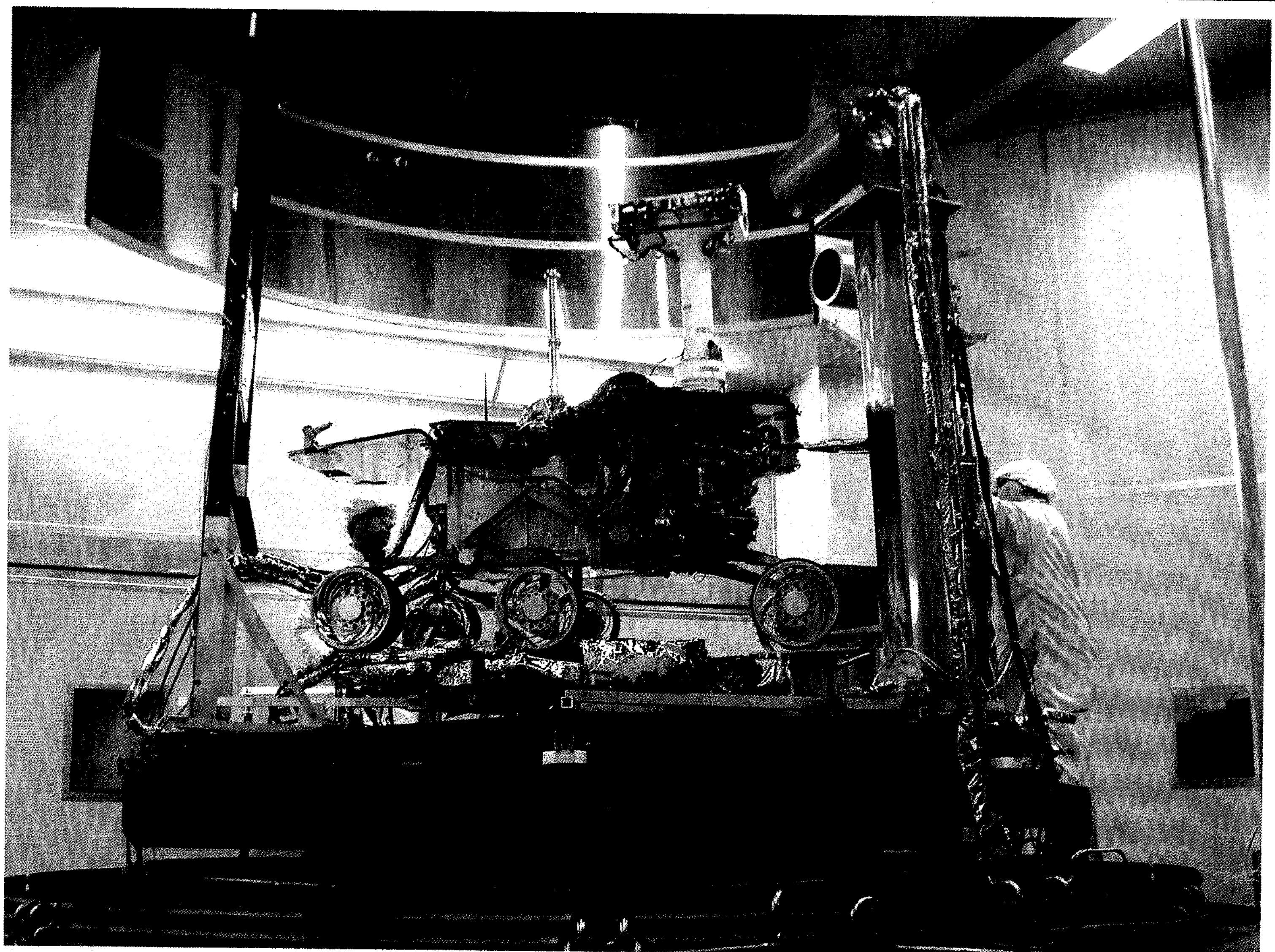

Rover 2 STT - Comparison Between Predicts and Test

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Test Case #5 - Cold Steady State (-95C Shrouds, -95C floor)
QREM = 15W, QMTES = 5.5W, QBATT = 10W

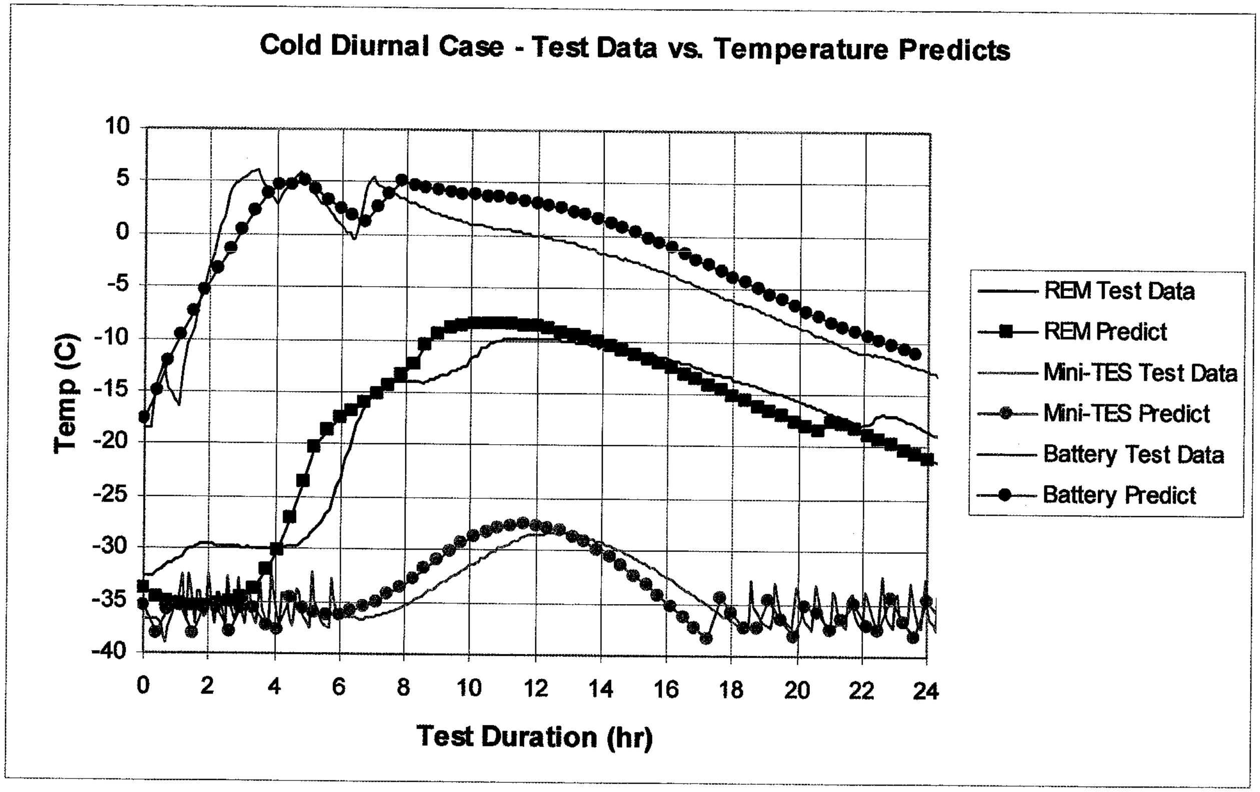
Hardware Item	Predicted Temp (C)	Test Temp (C)	Temp Diff (C)
REM	-34	-32	-2
Mini-TES	-35	-37	2
Rover Battery	-18	-18	0

Test Case #9 - Hot Steady State (0C Shrouds, 20C floor)
QREM = 17W, QMTES = 4.0W, QBATT = 1.1W

Hardware Item	Predicted Temp (C)	Test Temp (C)	Temp Diff (C)
REM	33	34	-1
Mini-TES	32	31	1
Rover Battery	23	23	0

Rover 2 STT - Cold Case Diurnal

Mars Exploration Rover



Case 11: Cold Diurnal Test (Duration: 24.7hr)

	REM Temp		Mini-TES Temp		Batt Temp	
	Max	Min	Max	Min	Max	Min
Test Data	-10	-33	-28	-39	6	-18
Test Predic	-8	-35	-28	-38	5	-18
Delta	2	2	0	1	1	0

Rover 2 STT - Hot Case Diurnal

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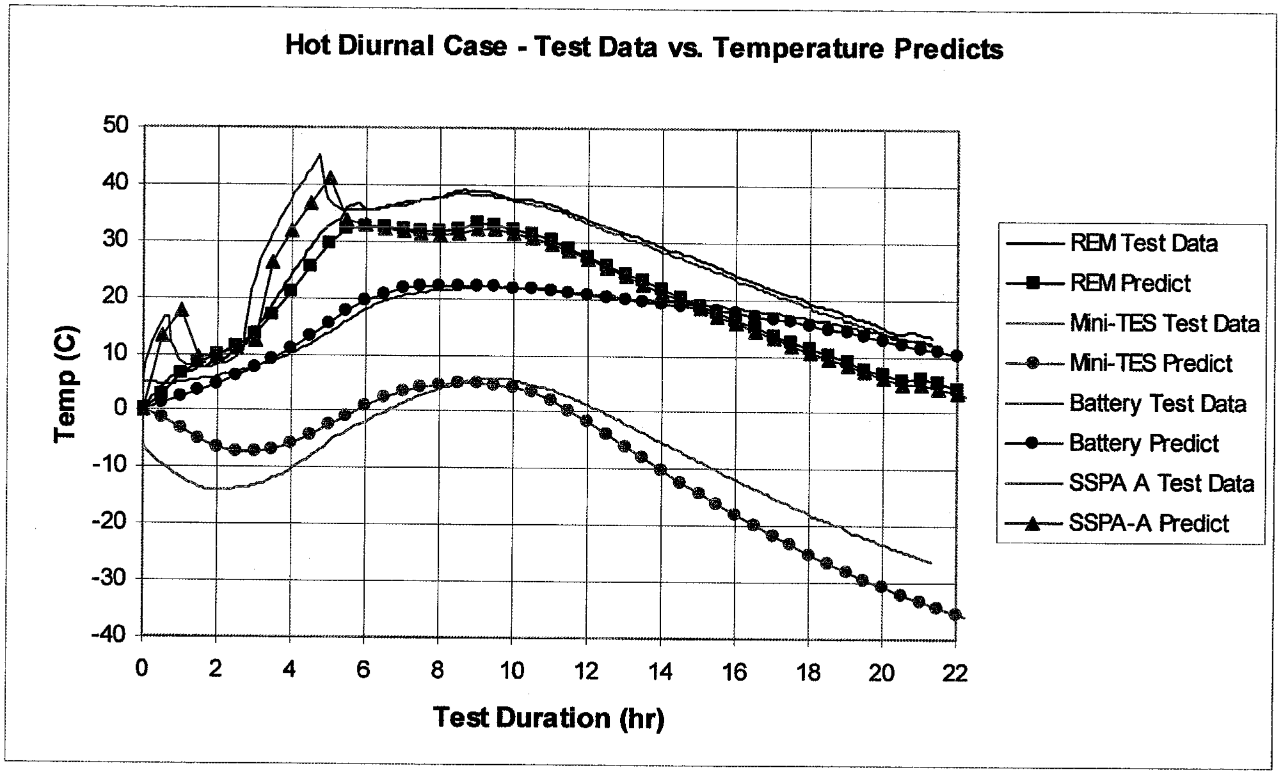

Case 11: Hot Diurnal Test (Duration: 21.9hr)

	REM Temp		Mini-TES Temp		Batt Temp		SSPA-A Temp	
	Max	Min	Max	Min	Max	Min	Max	Min
Test Data	39	1	6	-26	22	5	45	6
Test Predict	33	0	5	-36	22	0	41	0
Delta	6	1	1	10	0	5	4	6

Epilogue

- **Both flight systems are at KSC undergoing assembly for launch**
- **Flight hardware can humble the most experienced engineer**
- **System thermal test program was an overwhelming success**
  - **9 system-level tests performed over a 7-month period**
  - **No significant thermal design modifications required**