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Mars Exploration Rover

Thermal Design Overview of the Mars Exploration Rover Project

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Agenda

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- Configuration Overview
- Thermal Environments
- Driving Thermal Requirements
- Thermal Design Approach
- Thermal Control Block Diagram
- Thermal Design Description
- Thermal Analysis Results Summary
- Testing Plans
- Status

Flight System Configuration

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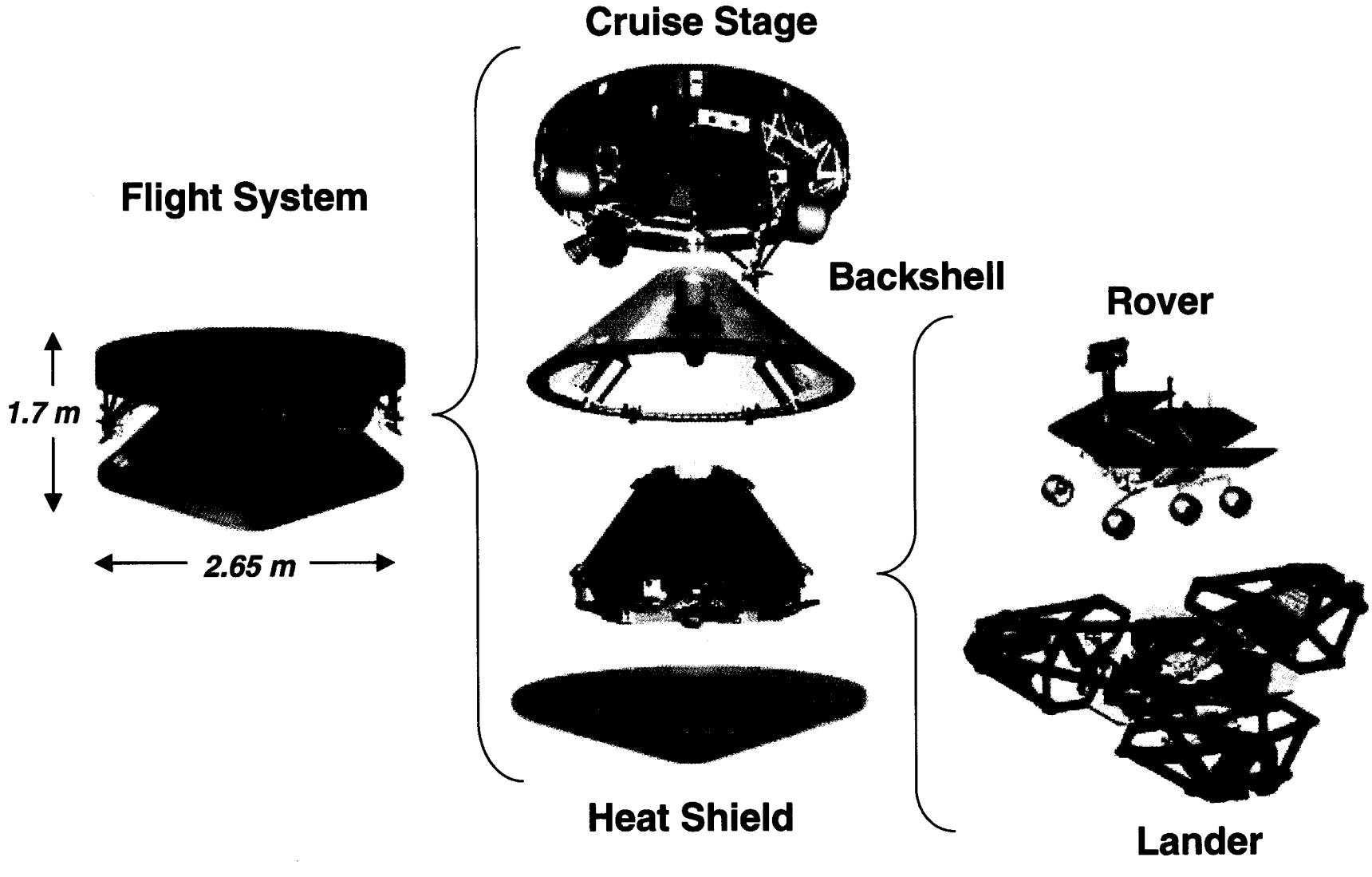

Spacecraft Cruise Configuration

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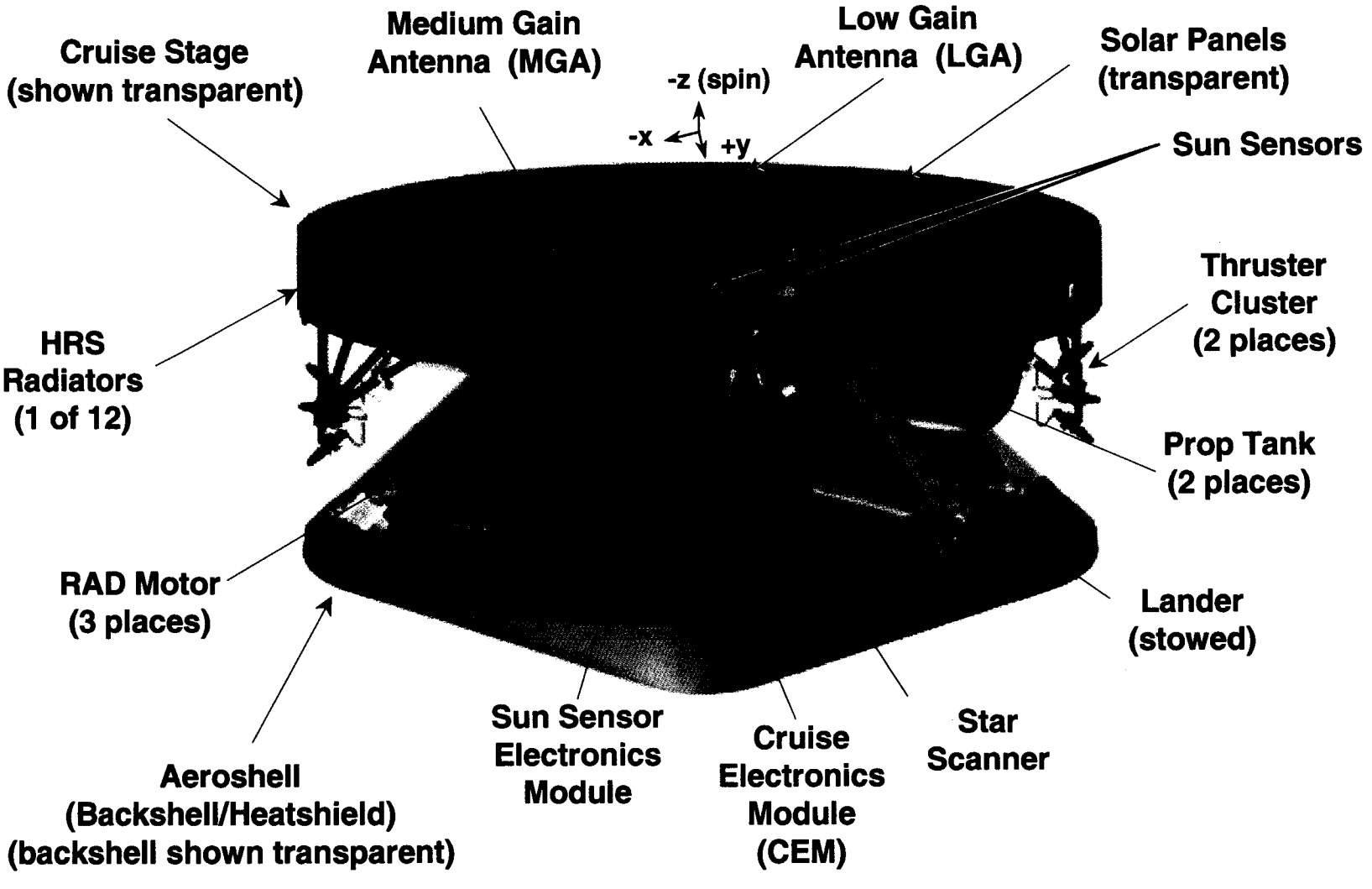

Cruise Stage Configuration

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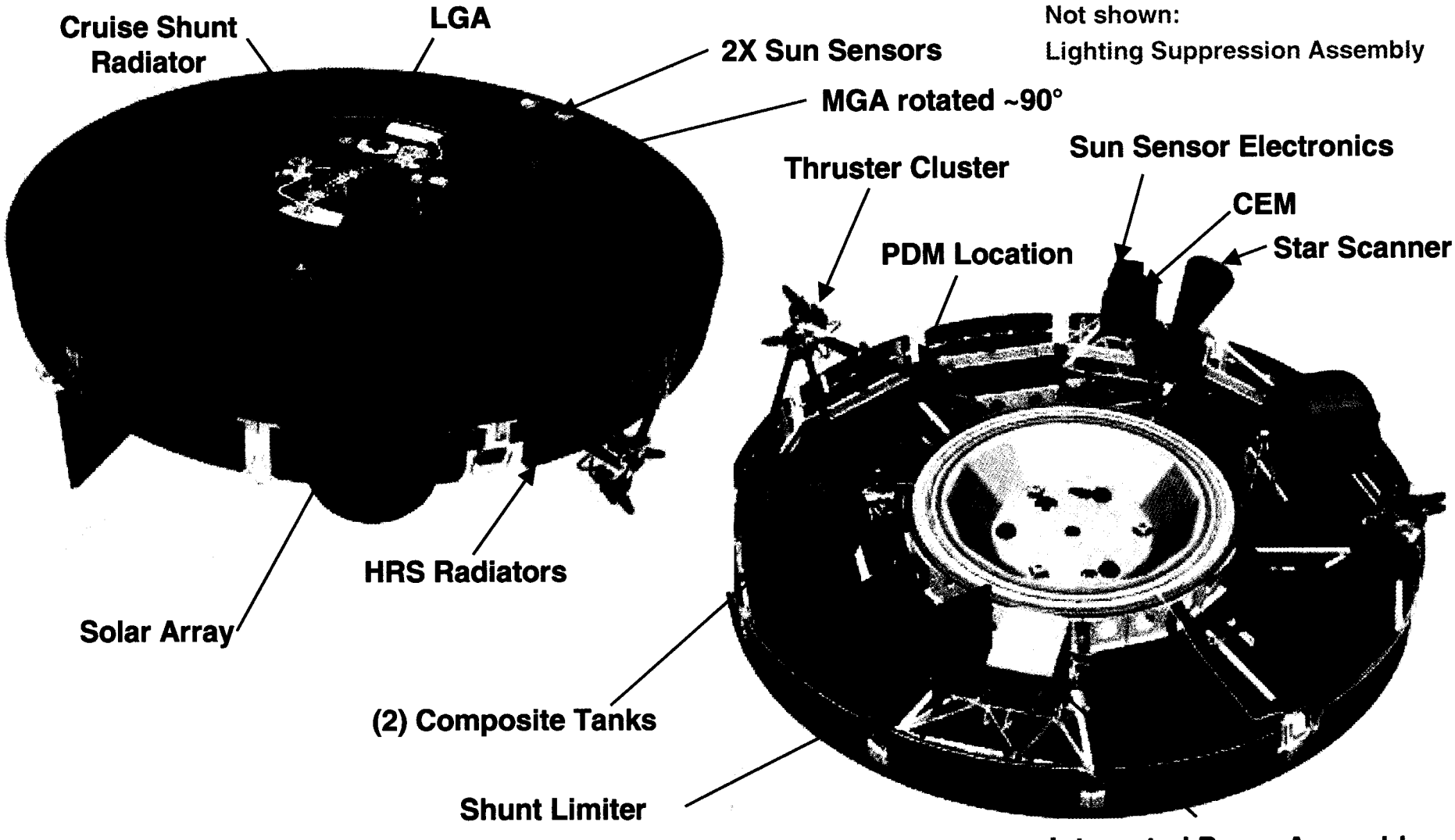

Aeroshell Configuration

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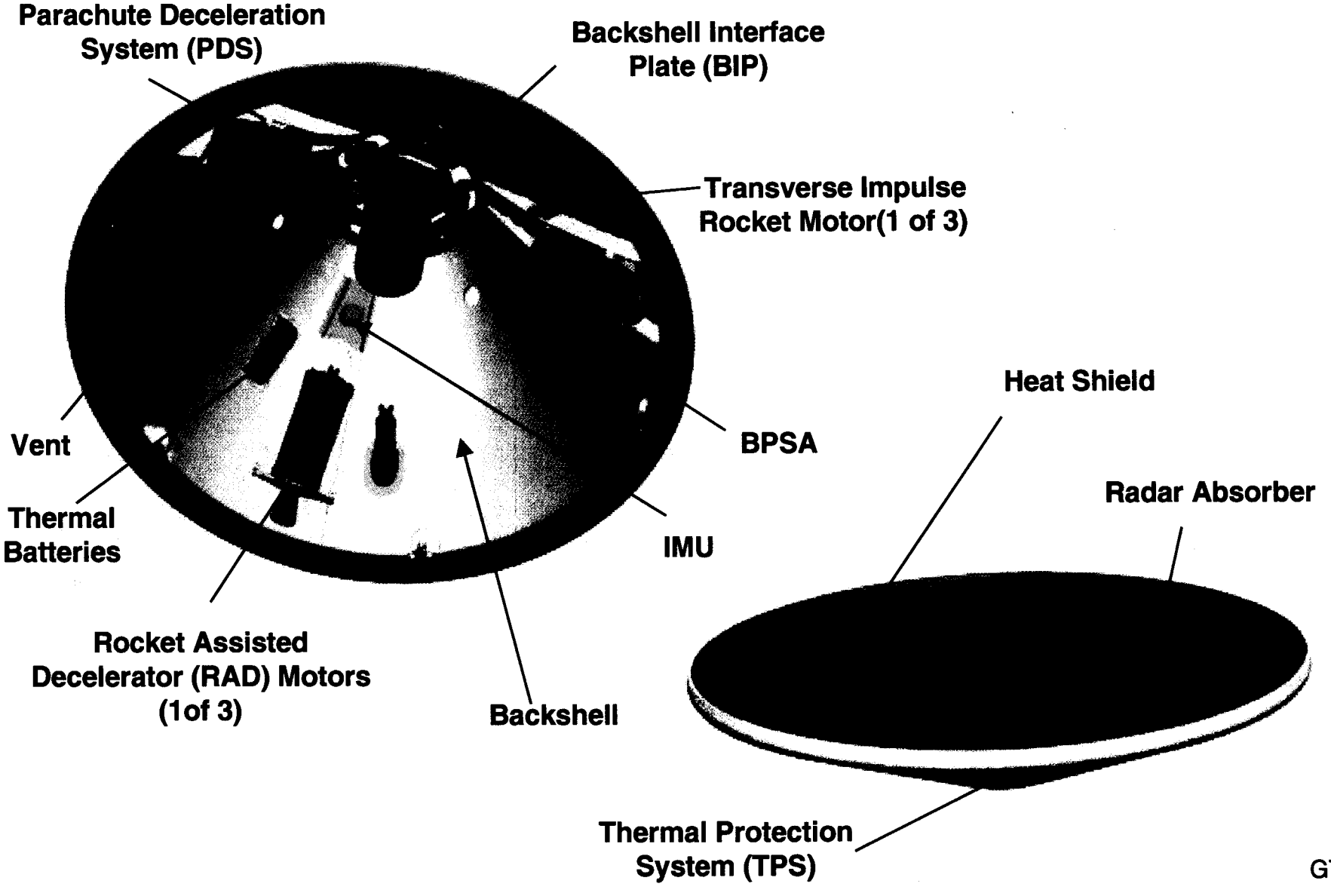

Lander Assembly - Stowed

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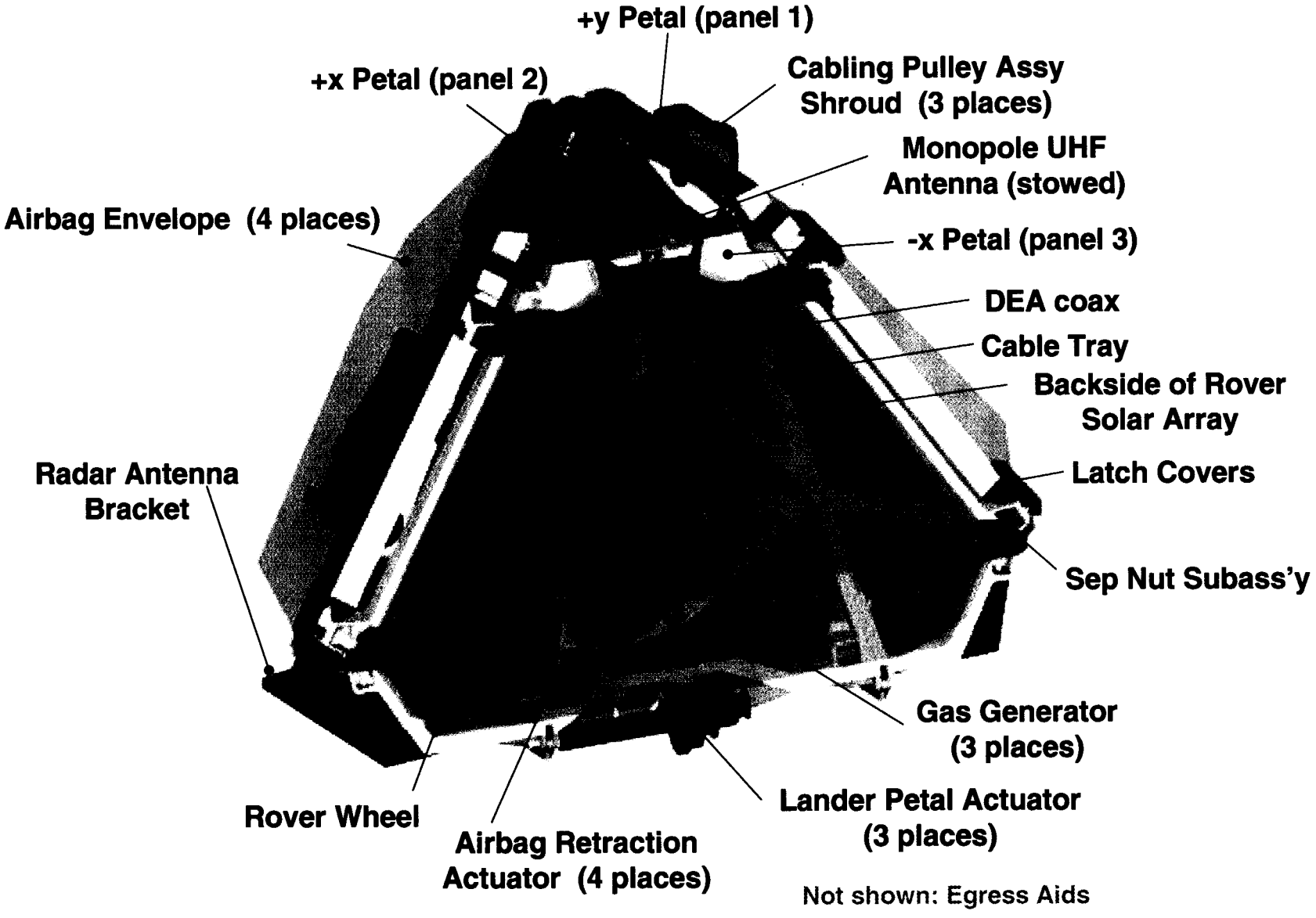

Not shown: Egress Aids

Lander Assembly - Deployed

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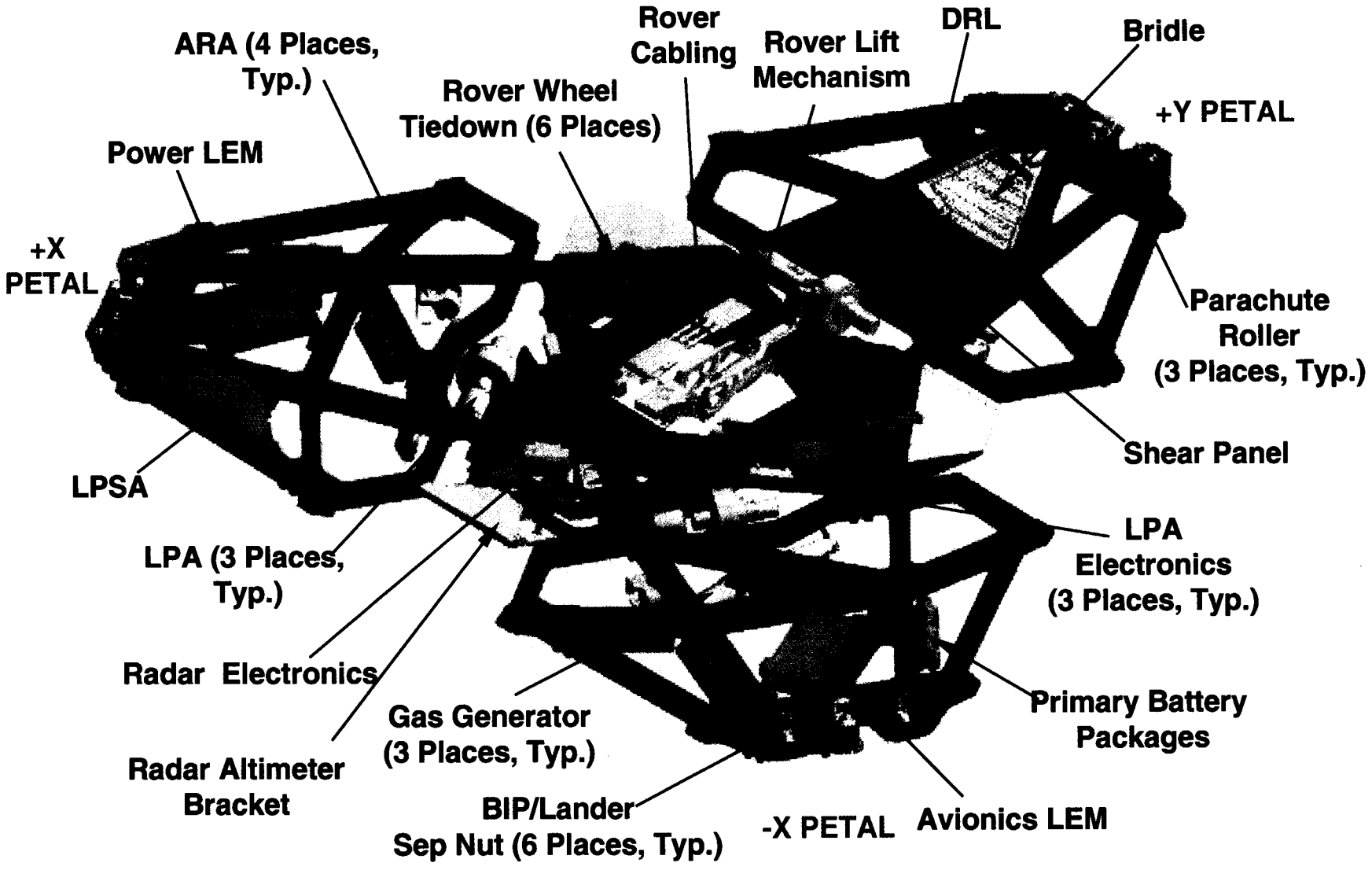

Rover Configuration - Deployed

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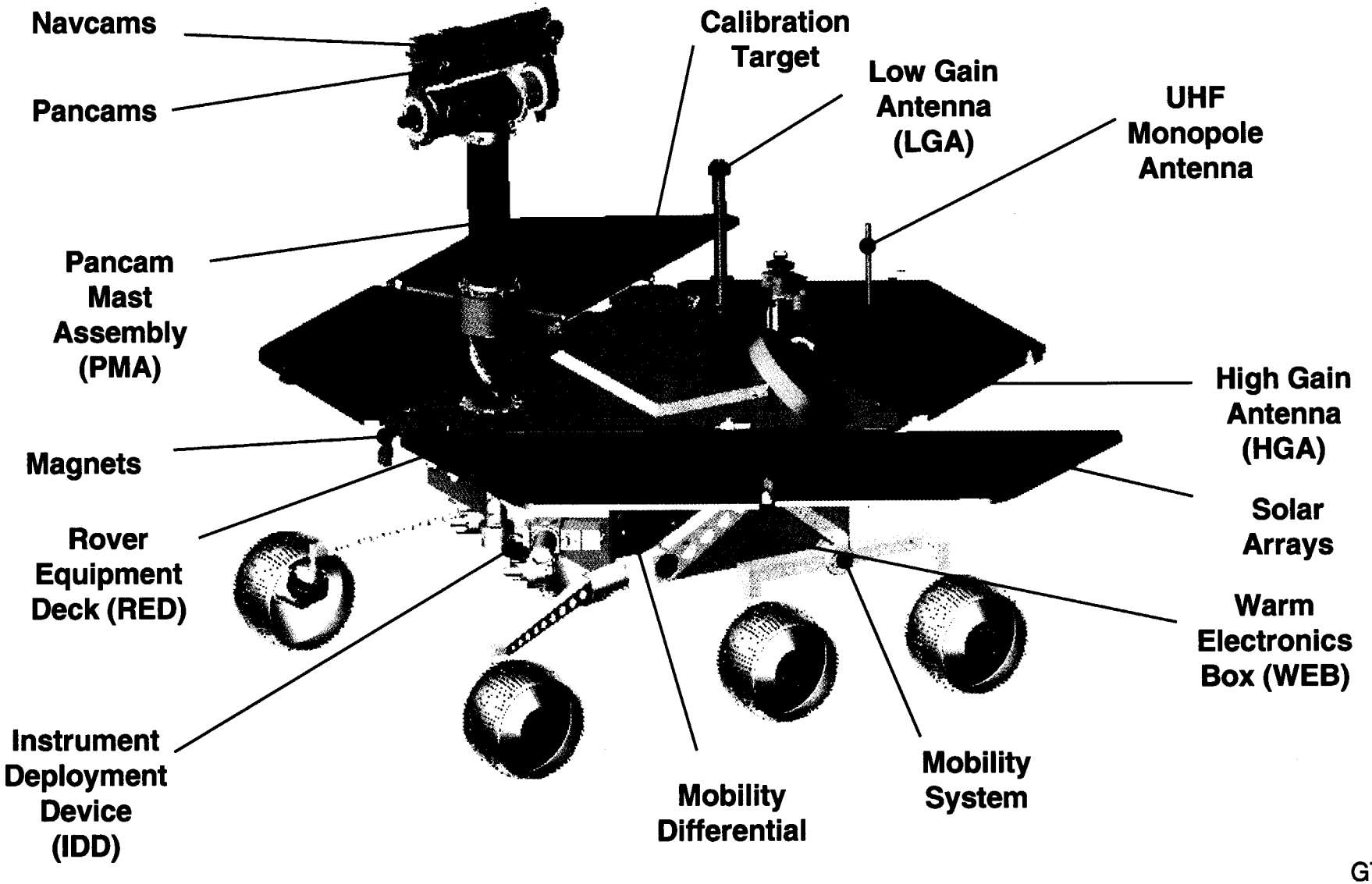

Isometric View of the WEB

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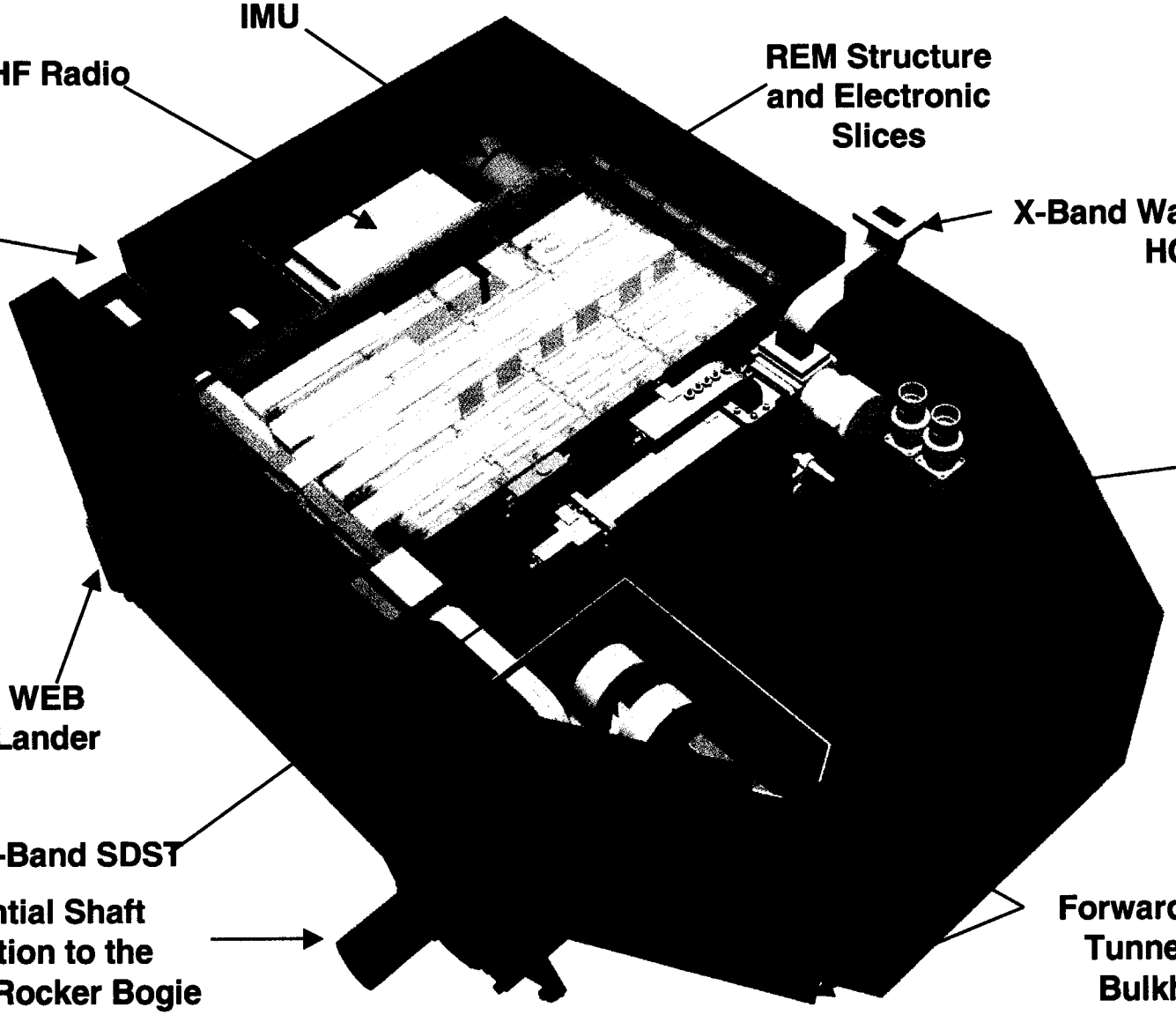

Thermal Environment

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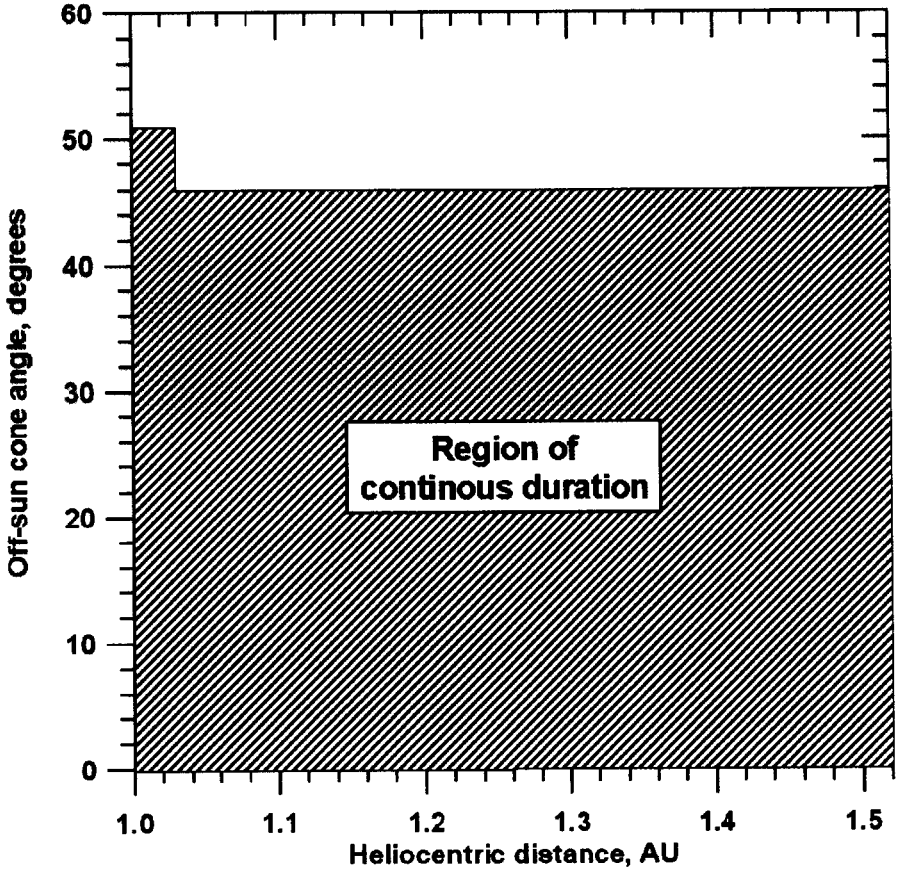
- **Off-sun during cruise requirements:**
  - **Continuous: 0° to 51° off-sun cone angle**
    - **Launch to Launch + 21 days: up to 51°**
    - **Launch + 22 day to Mars turn-to-Entry: 0° to 46°**
  - **Transient off-sun cone angles & durations**
    - **TCM1: 90° for up to 110 minutes at 1.02 AU**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



Thermal Environment (cont'd)

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- **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/m^2**
  - **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

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- **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**
    - **Tighest 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**

DOORS ID	*Requirement*	*Status*
888	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	Comply by design & analysis

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

DOORS ID	*Requirement*	*Status*
607	The Flight System shall be capable of operating the HGA actuators at 10 am Mars local time without additional warmup.	Comply by design & analysis

Blue text denotes changes from Project PDR

Thermal System Block Diagram

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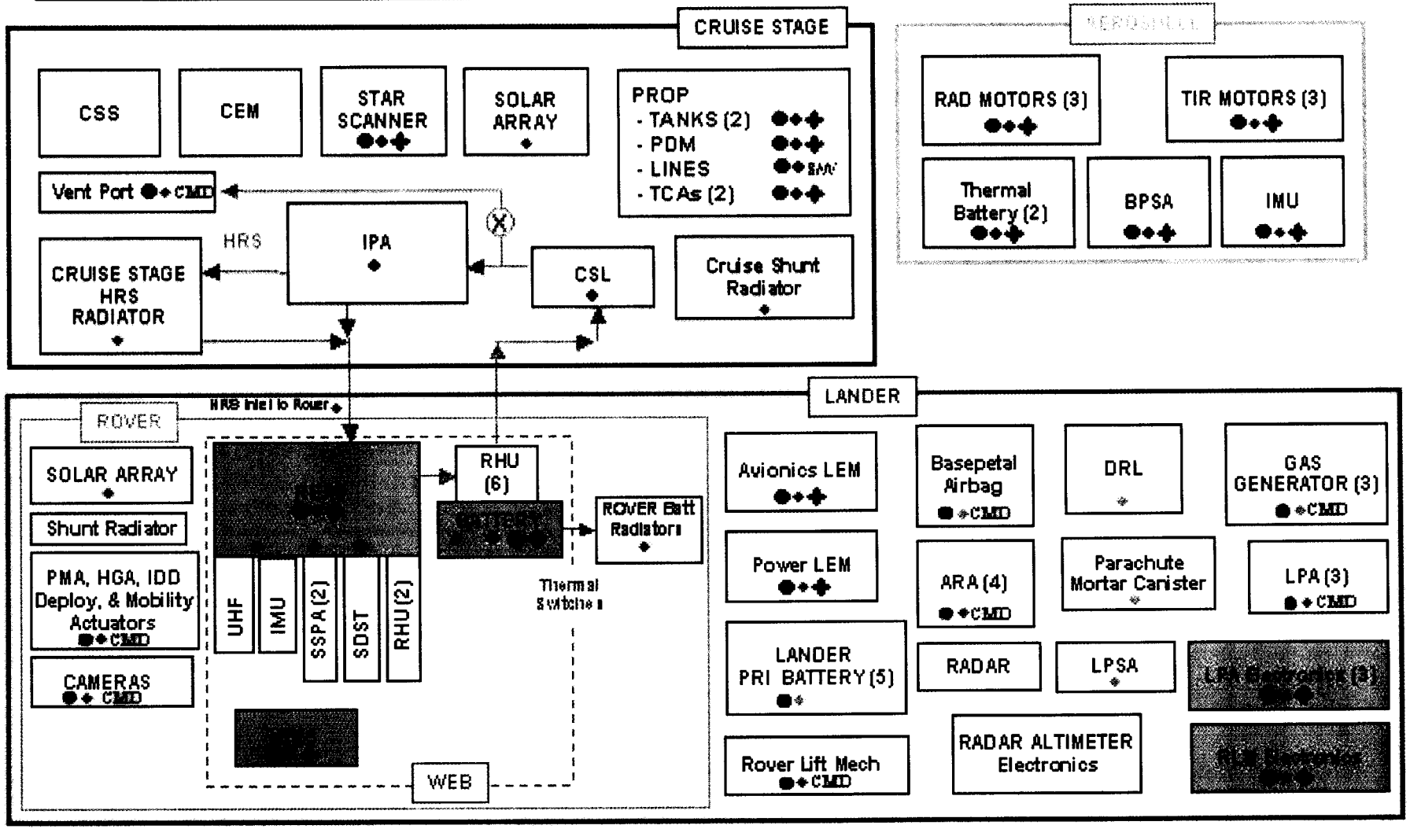

- Cruise Heater
- Warm-up Heater
- PRE EDL Heater
- Surf Op Heater

SW FSW Controlled
CMD Commandable
Nighttime heater usage
HRS Vent Valve

Mechanical Thermostat (Dual Redundancy)
Mechanical Thermostat(Single String)
- FRT (Read by the CEM REU)
- FRT (Read by the CSID/CPCU)

- FRT (Read by the LEM REU)
- FRT (Read by the REM Payload I/F Board)
- FRT (Read by the BCB)

Cruise Stage Thermal Design Overview

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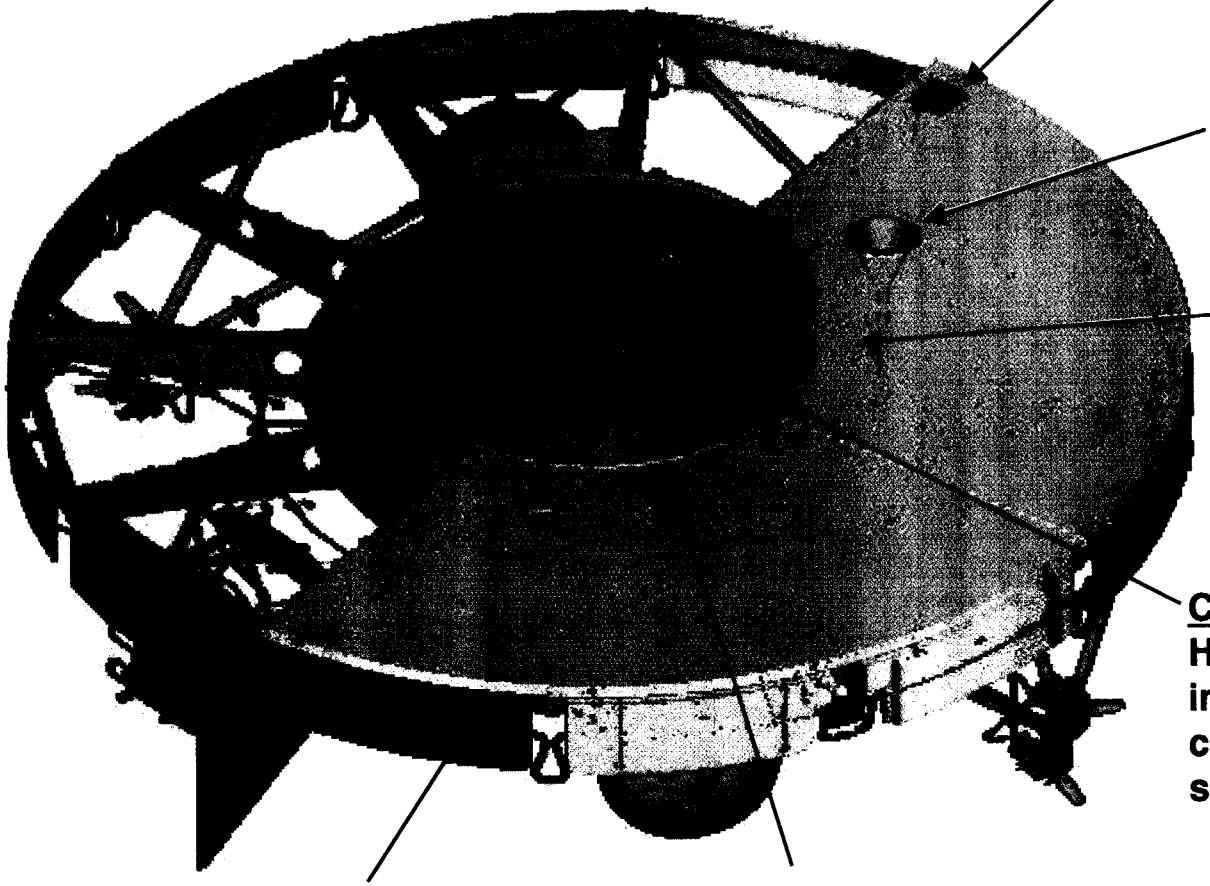

Sun Sensors:
Ag/FEP tape on top

MGA:
S13-GLO (white) paint on back

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

Cruise Shunt Radiator:
HINCOM paint including sep. spring covers, anodized L/V spring pads

HRS Radiators:
HINCOM paint on both sides

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

Cruise Stage Thermal Design Overview (cont'd)

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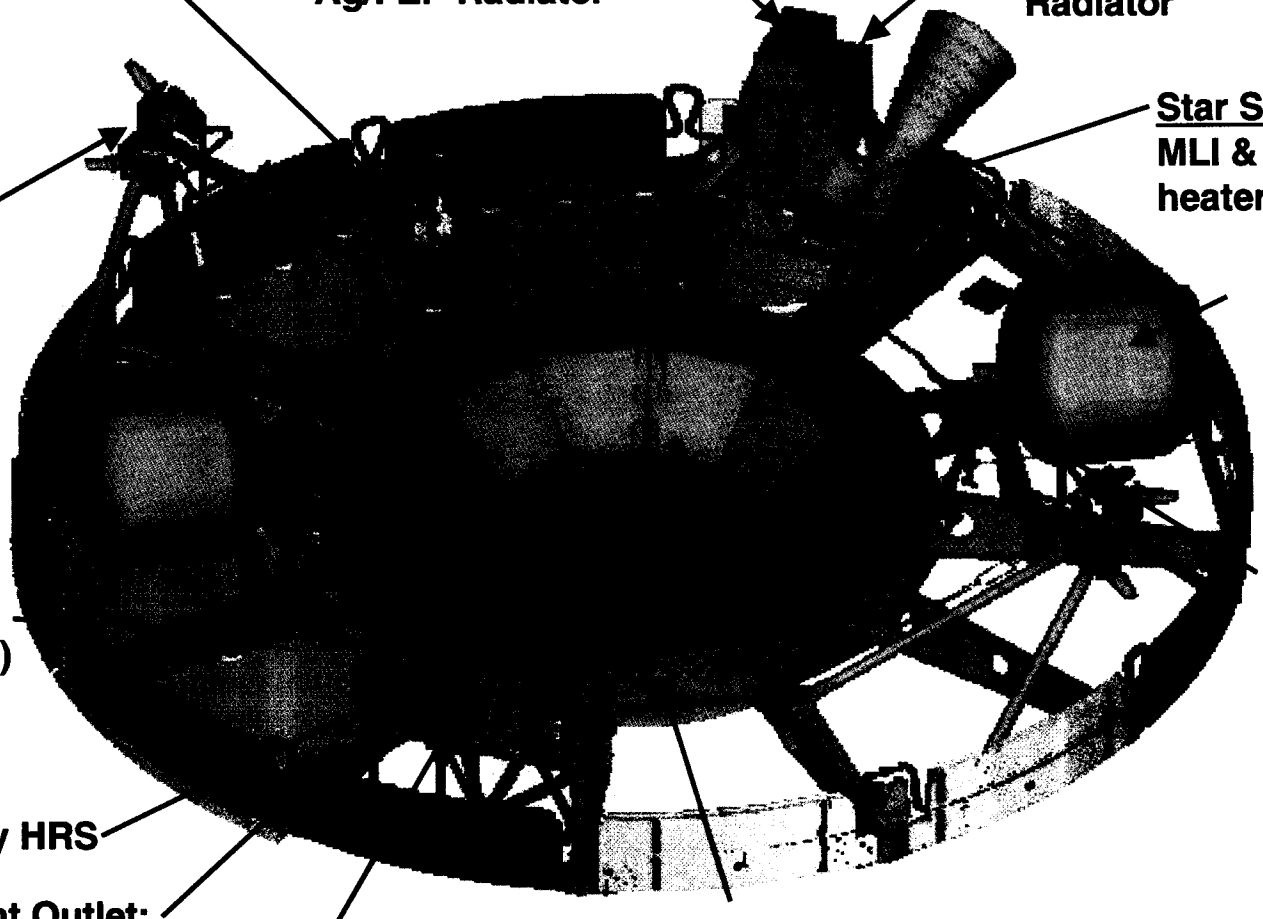

PDM: MLI & thermostatic heaters

Sun Sensor Elect.: MLI & Outward Ag/FEP Radiator

CEM: MLI & Outward Ag/FEP Radiator

Star Scanner: MLI & thermostatic heater

TCAs: MLI & thermostatic heaters

Propellant Tanks: MLI & thermostatic heaters

Propellant Lines: MLI, aluminum cladding, thermostatic FSW heater control for 8 zones

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

HRS Overview

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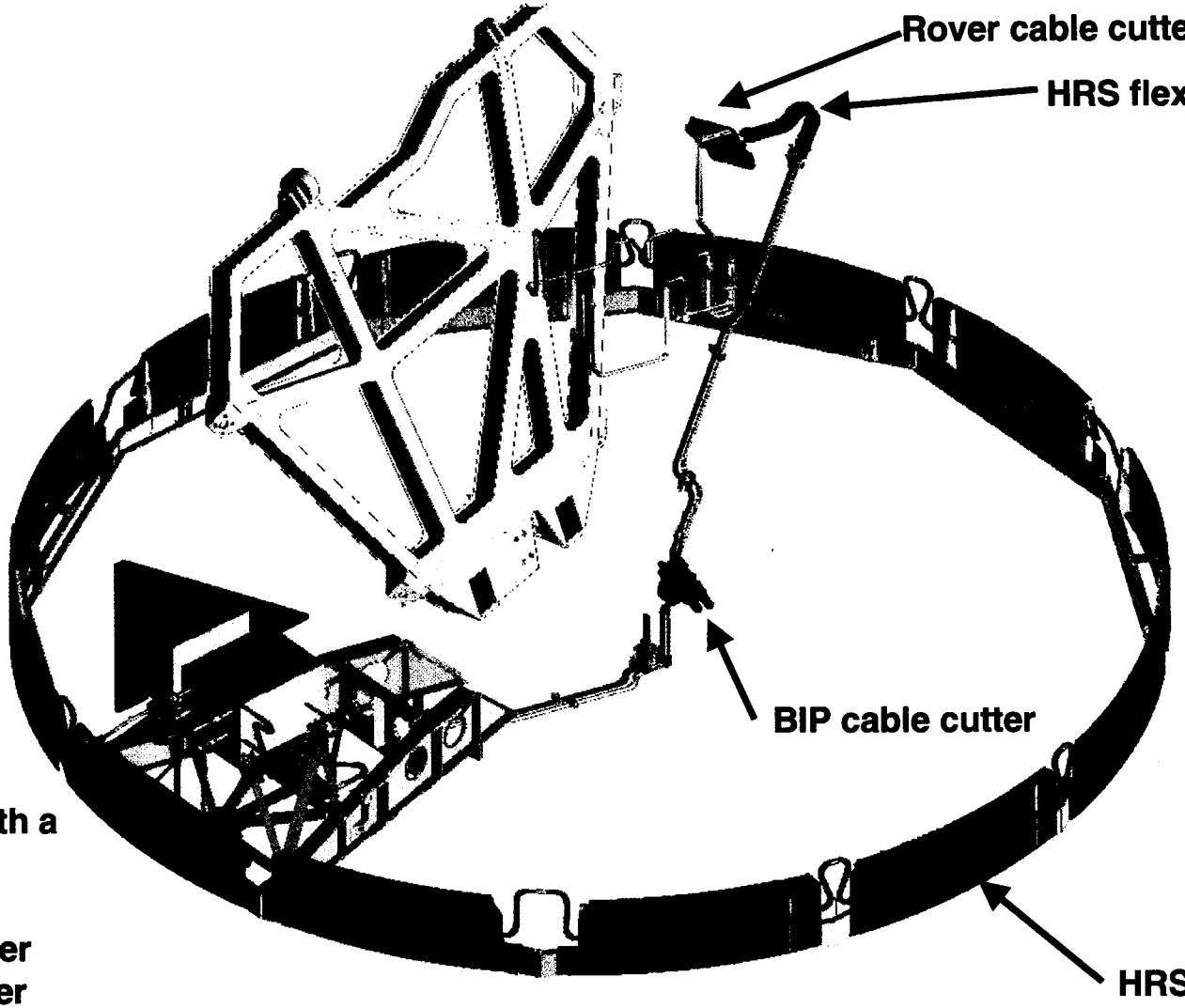

IVSR consists of:
- IVSR structure
- IPA
- 2 Pyro valves
- Filter in parallel with a relief valve
- Vent outlet
- Pressure transducer
- CSL heat exchanger
- CSL "shark fin" radiator

HRS Schematic

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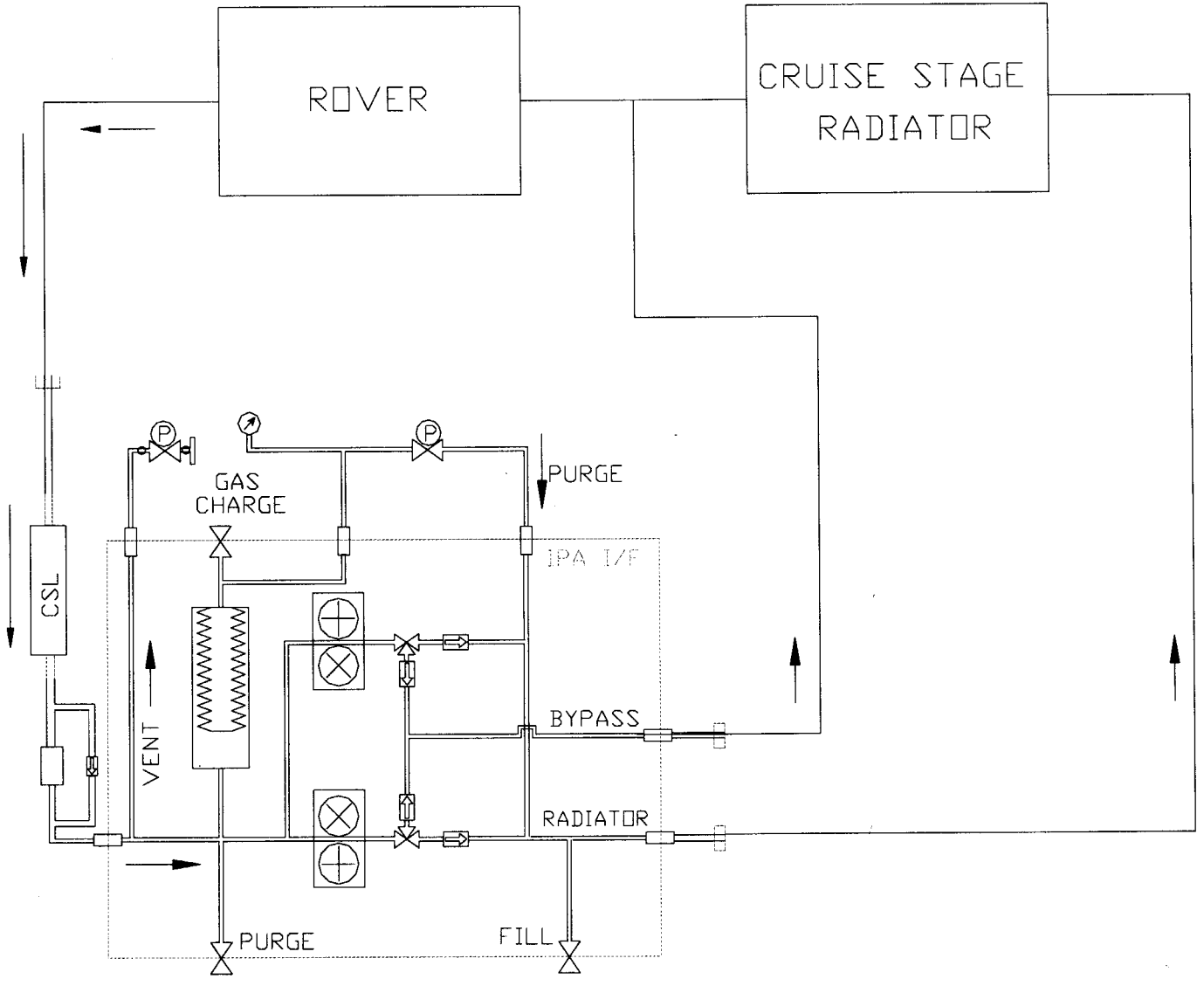

Integrated Pump Assembly

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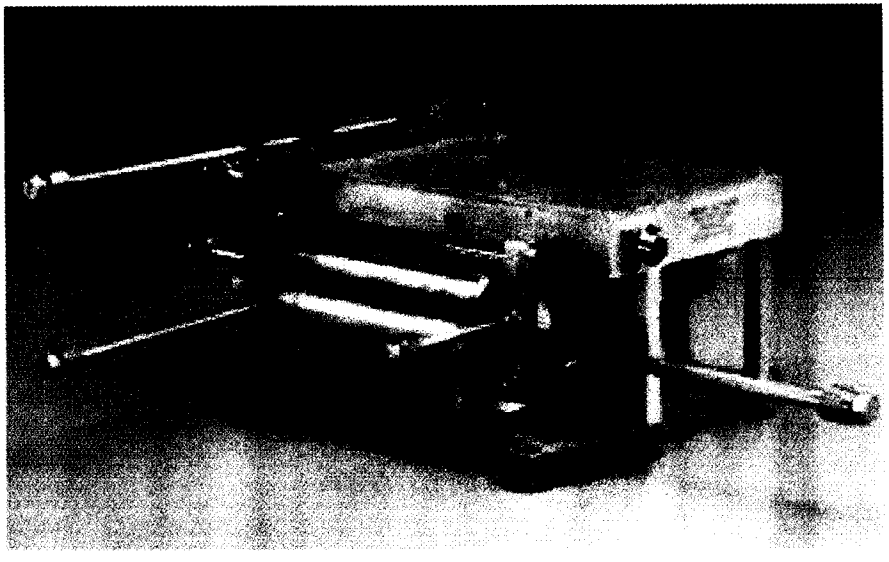

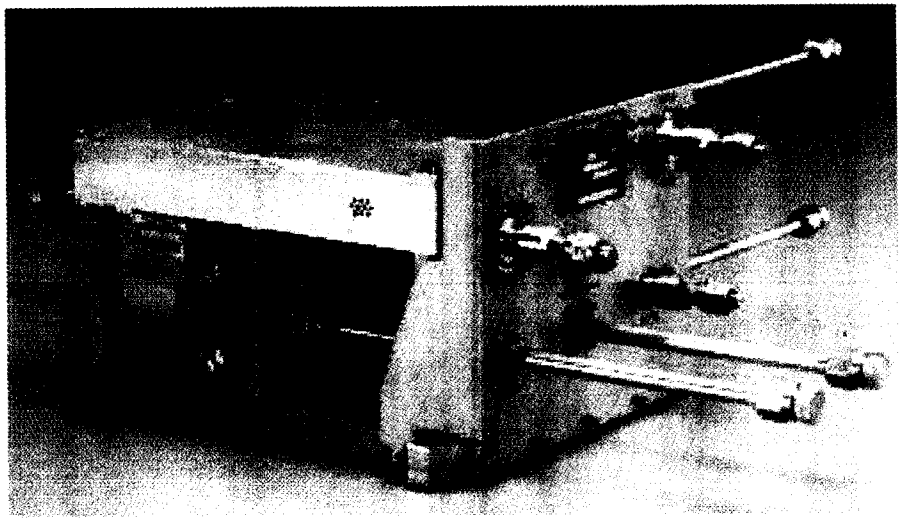

- **Mars Pathfinder IPA shown**
- **MER adopted a Mars Pathfinder build-to-print approach for the IPA**

Aeroshell Thermal Design Overview

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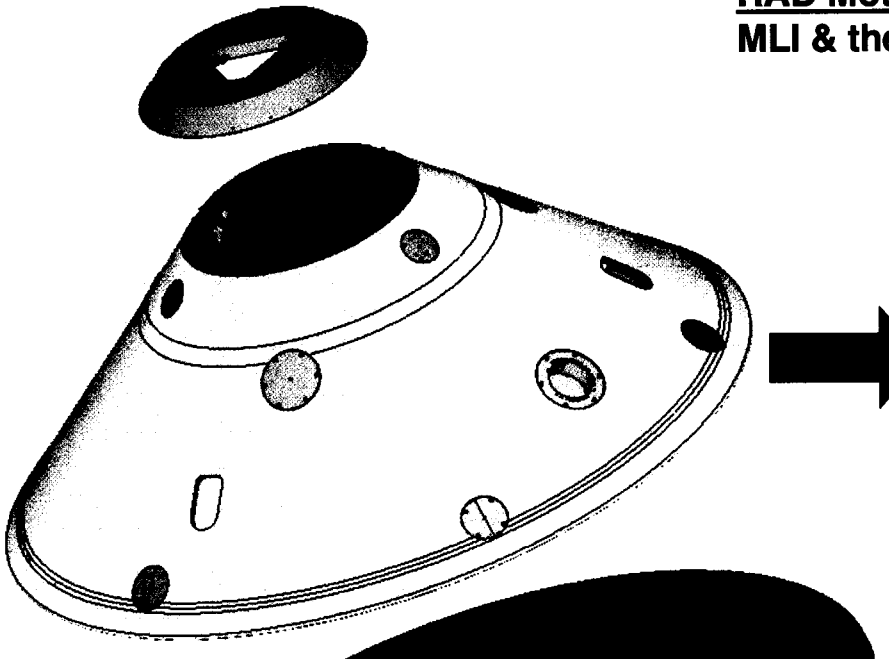

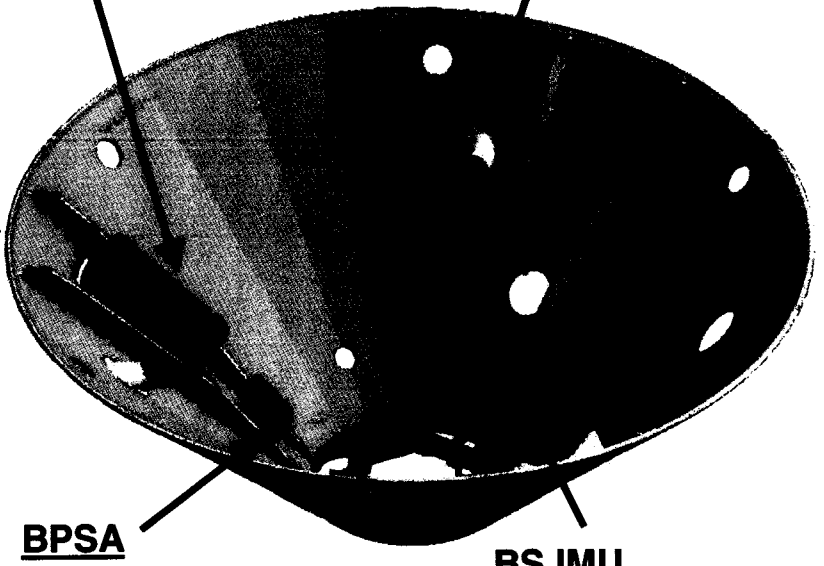

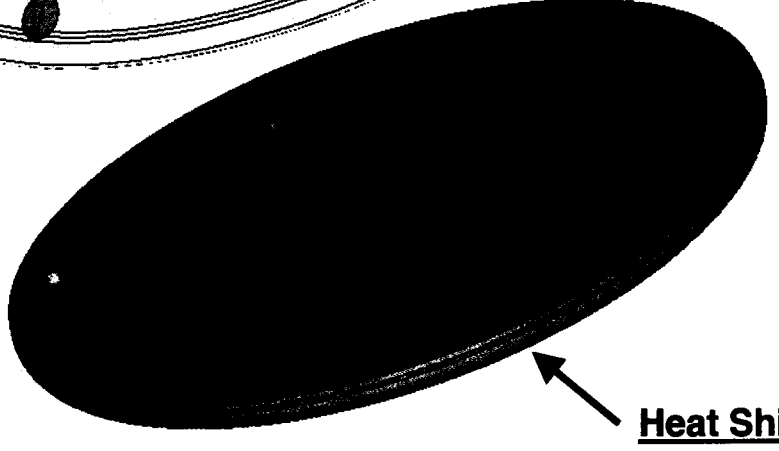

RAD Motors (3)
MLI & thermostatic heaters

TIRS Motors (3)
MLI & thermostatic heaters

BPSA
Thermostatic heaters
High ε finish

BS IMU
Thermostatic heaters
Mounting plate mass

Thermal Battery (hidden)
MLI & thermostatic heaters

Heat Shield
Interior MLI
Exterior radiation shield

Lander Thermal Design Overview

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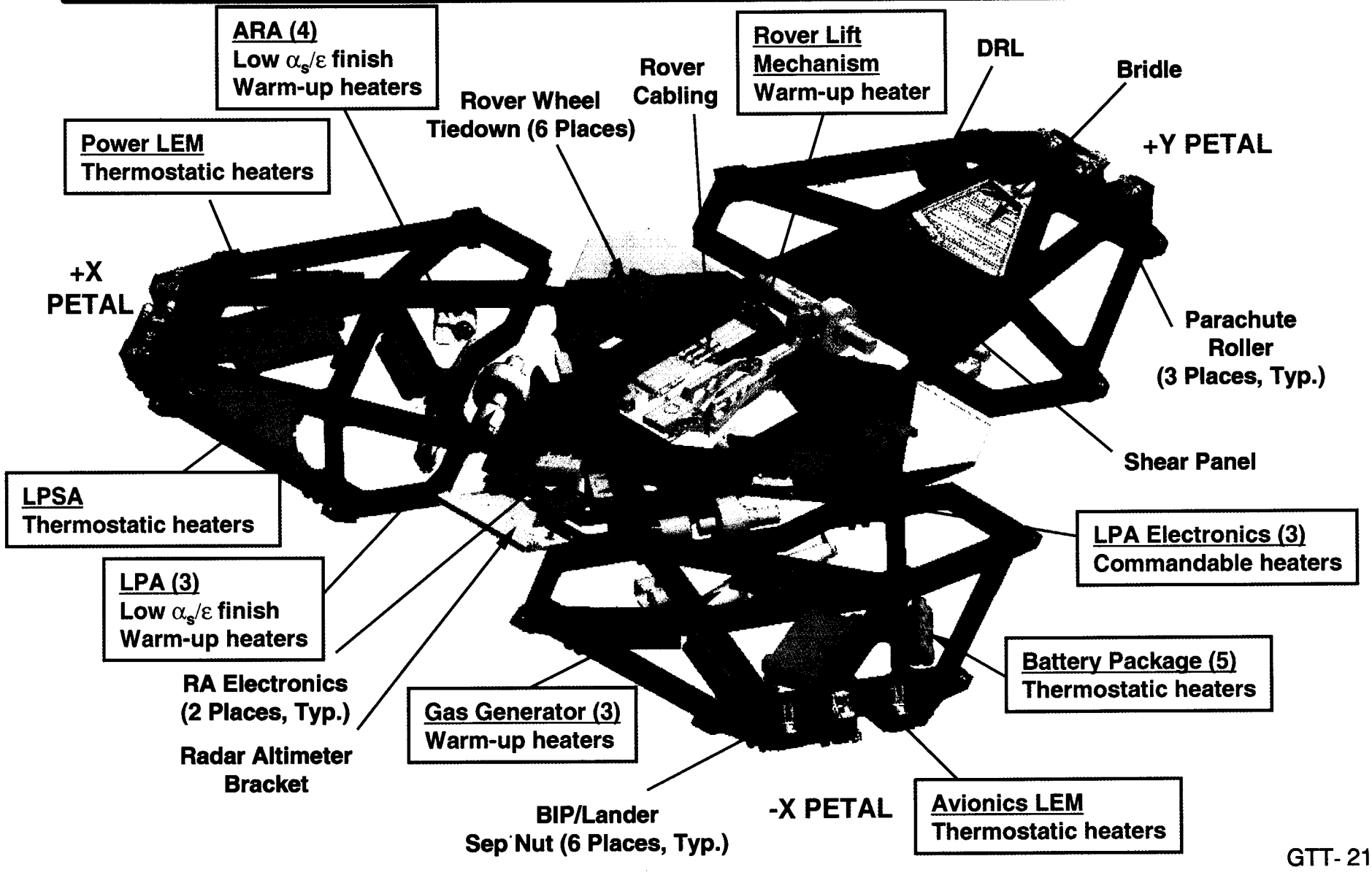

Rover Thermal Design Overview

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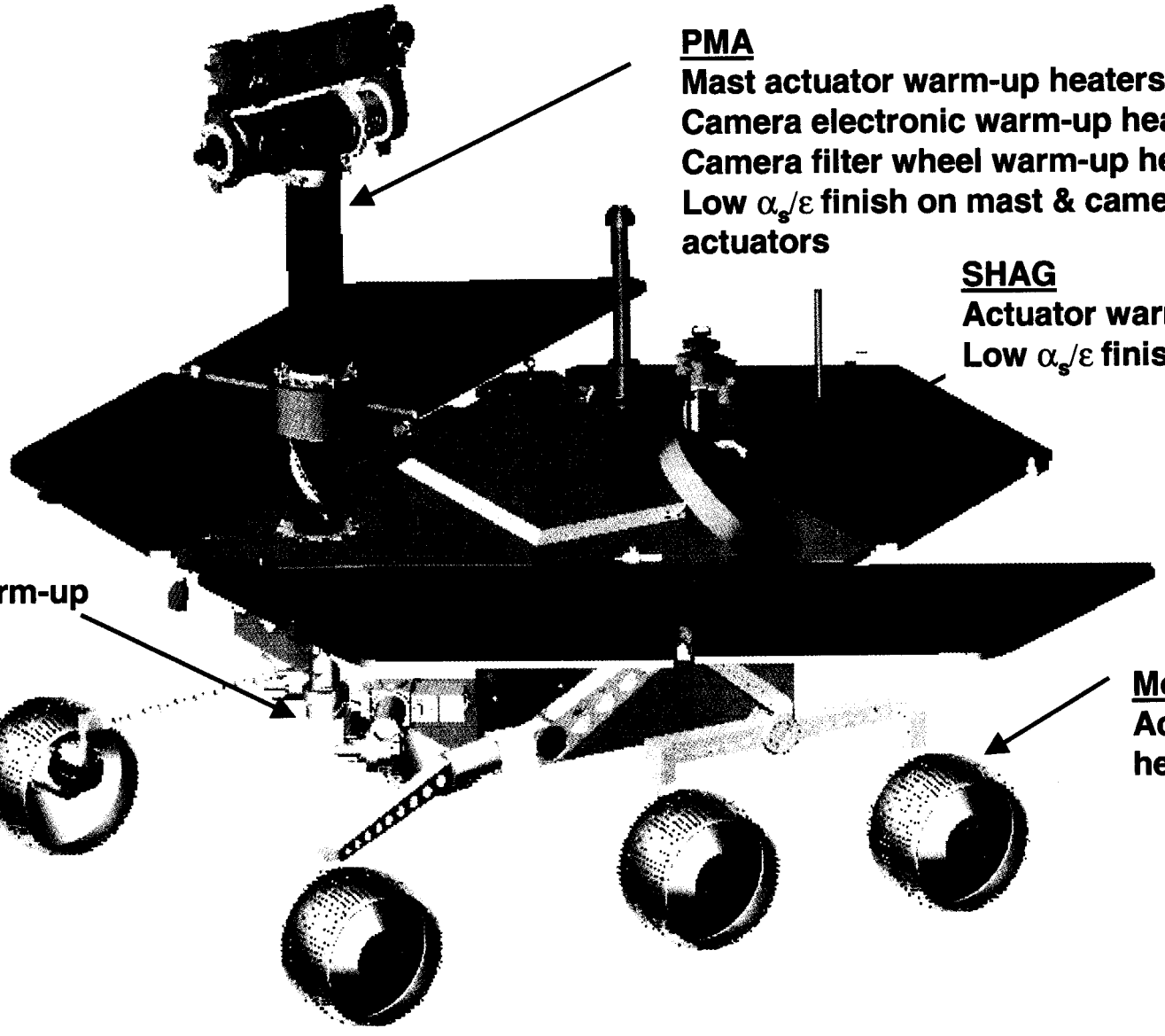

PMA
Mast actuator warm-up heaters
Camera electronic warm-up heaters
Camera filter wheel warm-up heaters
Low α_s/ε finish on mast & camera actuators

SHAG
Actuator warm-up heater
Low α_s/ε finish on actuator

IDD
Actuator warm-up heaters

Mobility
Actuator warm-up heaters

Rover Thermal Design Overview (cont'd)

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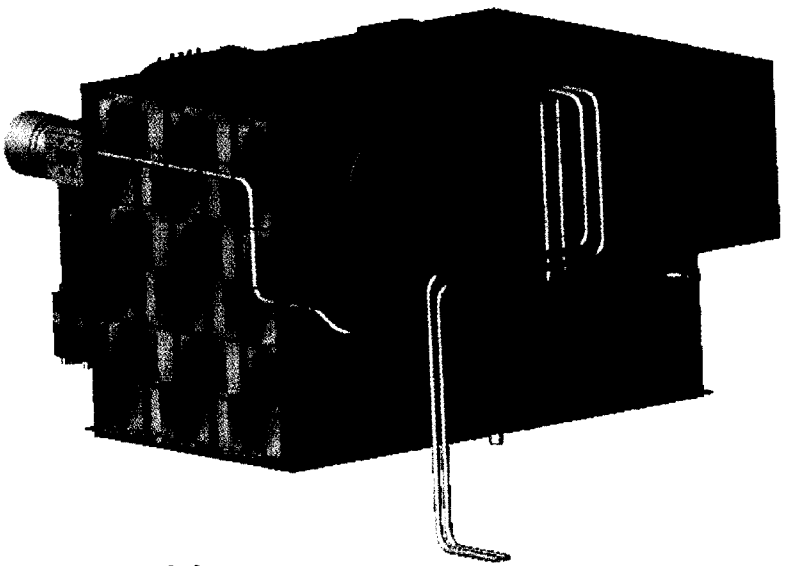
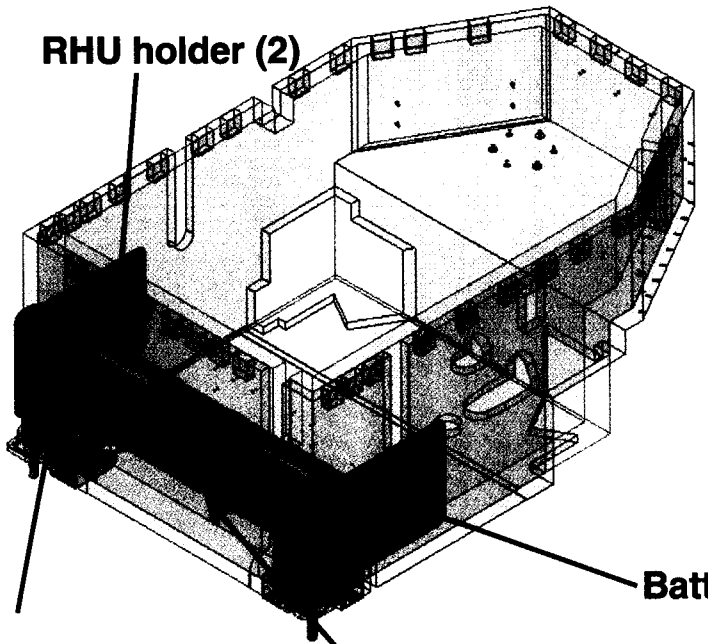
WEB DESIGN FEATURES

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

HRS tubing on REM





Subsystem Test Plans

- **Rover/HRS Thermal Characterization Test Overview**
  - **Test scheduled to start 4/1/02 for one month**
  - **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)

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- **System T/B Test Overview**

– S/C Cruise 1	9/25/02	Design verification
– Rover 2	10/14/02	Design verification
– S/C Cruise 2	11/20/02	Limited workmanship
– Rover 1 & 2	1/29/03	Workmanship

- **First two tests involve thermal design verification**
  - No thermal margin testing planned
- **Last two tests are workmanship tests**
  - Cruise 2 uses flight CS, EM Lander & Rover simulator
- **IR lamps used to simulate off-sun environmental heating during cruise and Mars solar environmental heating during landed operations**

Status

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- Assembly, Test, & Launch Operations (ATLO) Phase started on 3/4/02
  - Majority of system-level thermal design is complete
- IVSR structure starting initial assembly
- IPA undergoing assembly
  - Controller electronics environmental test in progress
- Heat switch delivery expected by 3/15/02
- All temperature sensors received and delivery to subsystem users in progress
- Majority of heaters and thermostat received
- Delivery of Rover/HRS test articles in progress