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Thermal Engineering for the Beagle 2 Mars Lander Surface Operations

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Acknowledgment

- Dr Simon Peskett, who preceded me as lead thermal engineer on Beagle 2 until he left RAL at the end of 2001.

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Mission Overview

- Launched June 2003 aboard ESA's Mars Express – to look specifically for signs of life. Seven month Cruise, followed by five day Coast (no telemetry available)
- Landing site in the Isidis Basin (11°N 90°E)
- Early spring northern hemisphere (Ls = 322°). Baseline mission of 180 Sols (to Ls = 60°)
- Landing planned for Christmas morning 2003 but no communication achieved with Beagle 2

Landed Configuration

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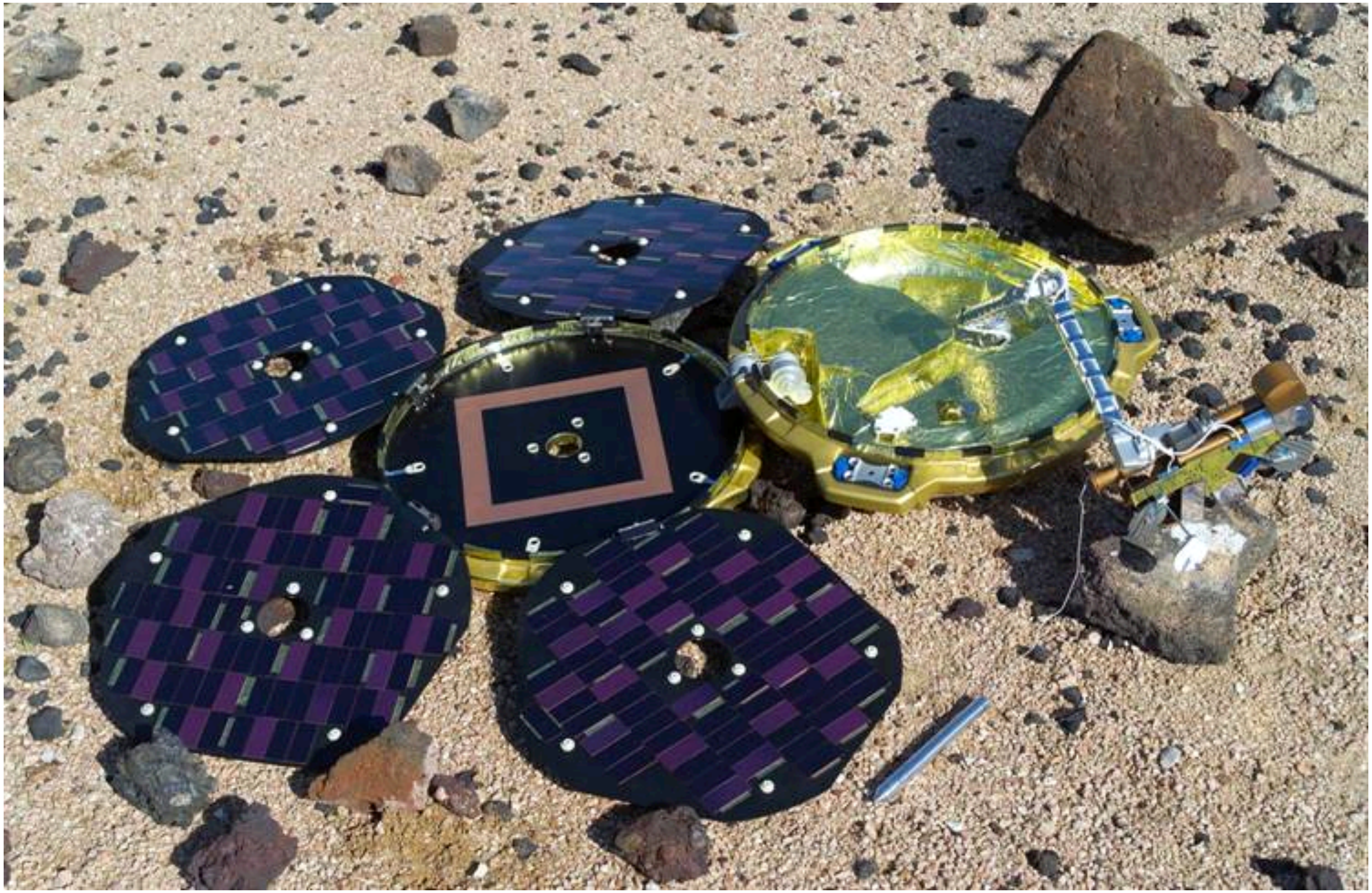
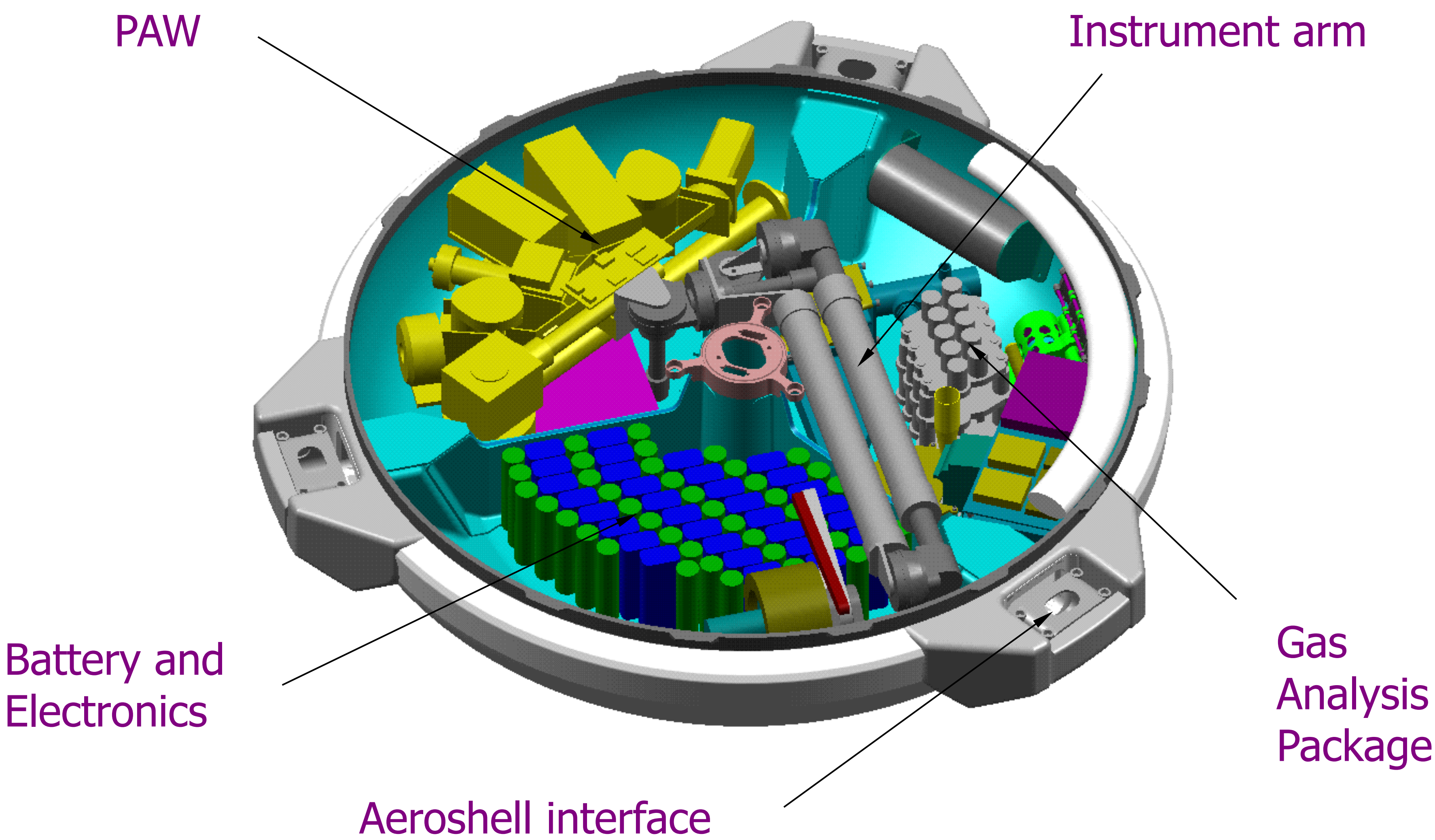


Lander model on the NASA Johnson Space Centre Mars Simulation Surface

Inside the Lander



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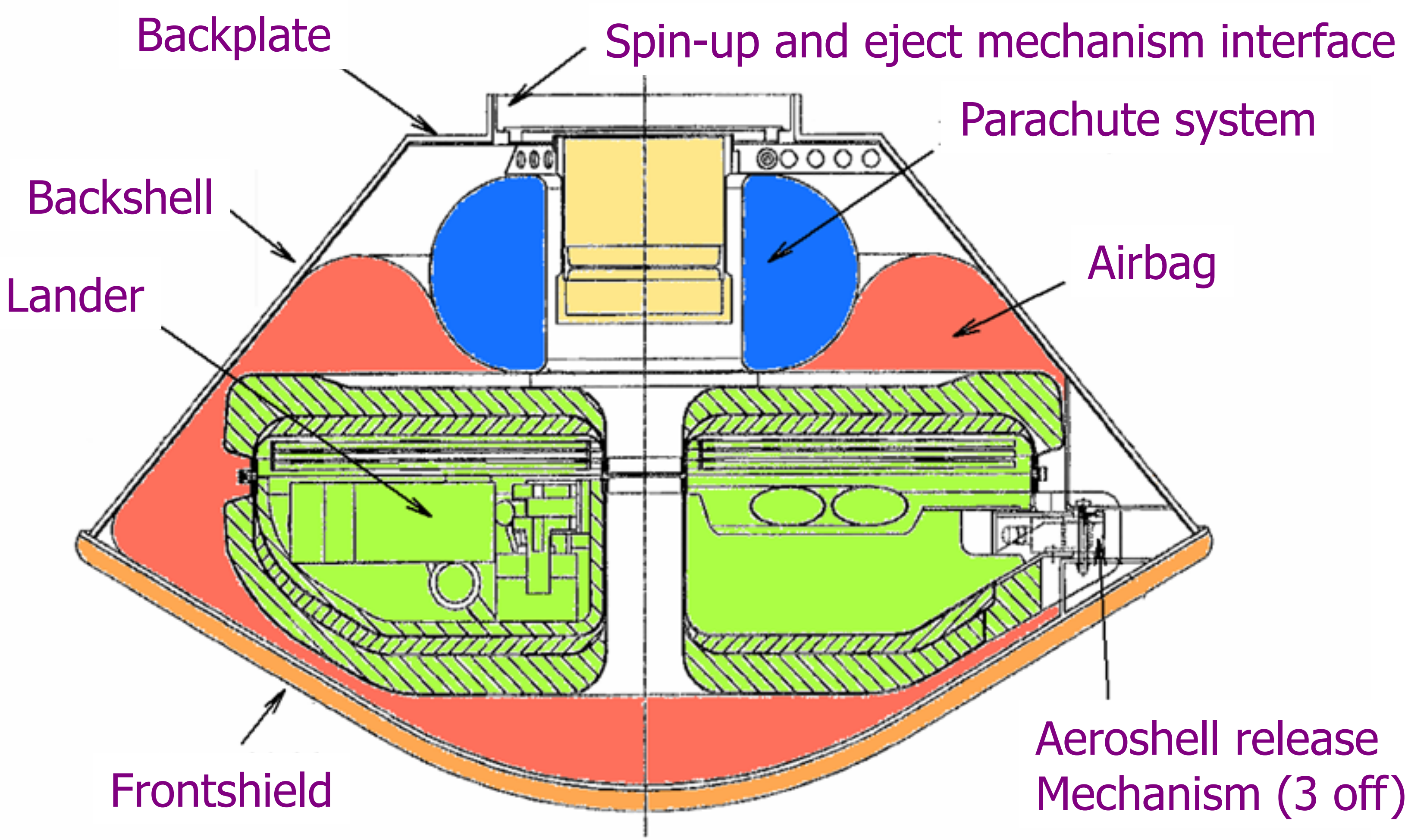
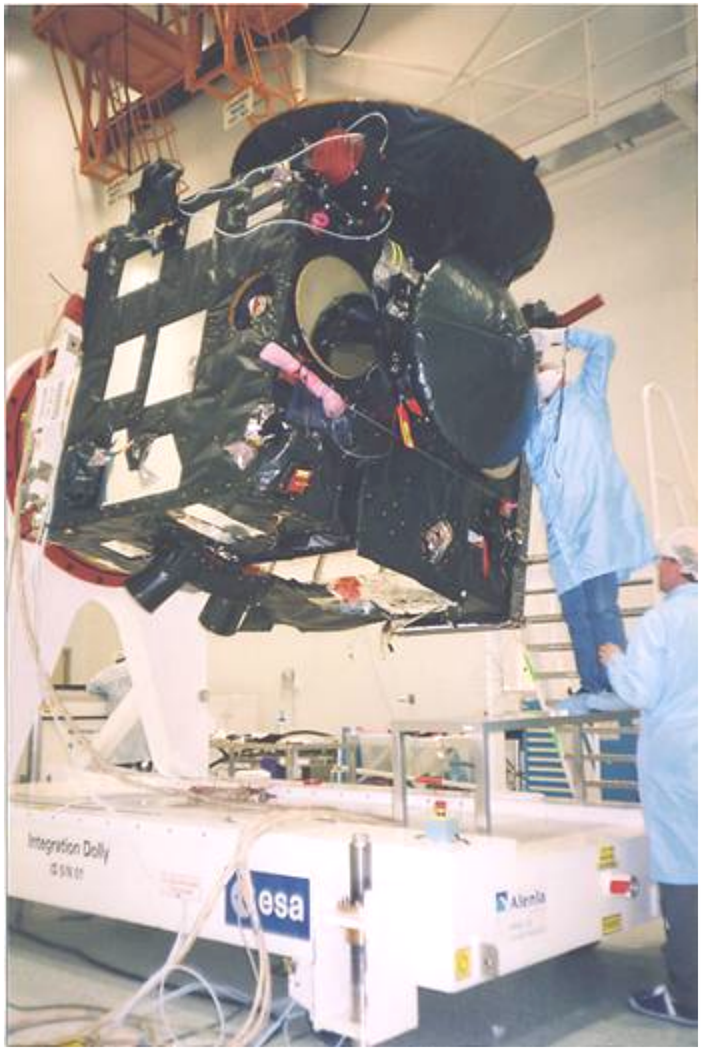
Beagle 2 Science Summary

- Beagle 2 was packed like a tourist’s suitcase!
- Examine soil, rocks, and atmosphere for evidence of life
  - Instrument arm
  - Beagle’s ‘PAW’ and the ‘Mole’
  - Gas Analysis Package
- Martian weather reports
- Age, chemistry, and composition of the Mars surface
- Cameras

Journey to Mars - the Probe

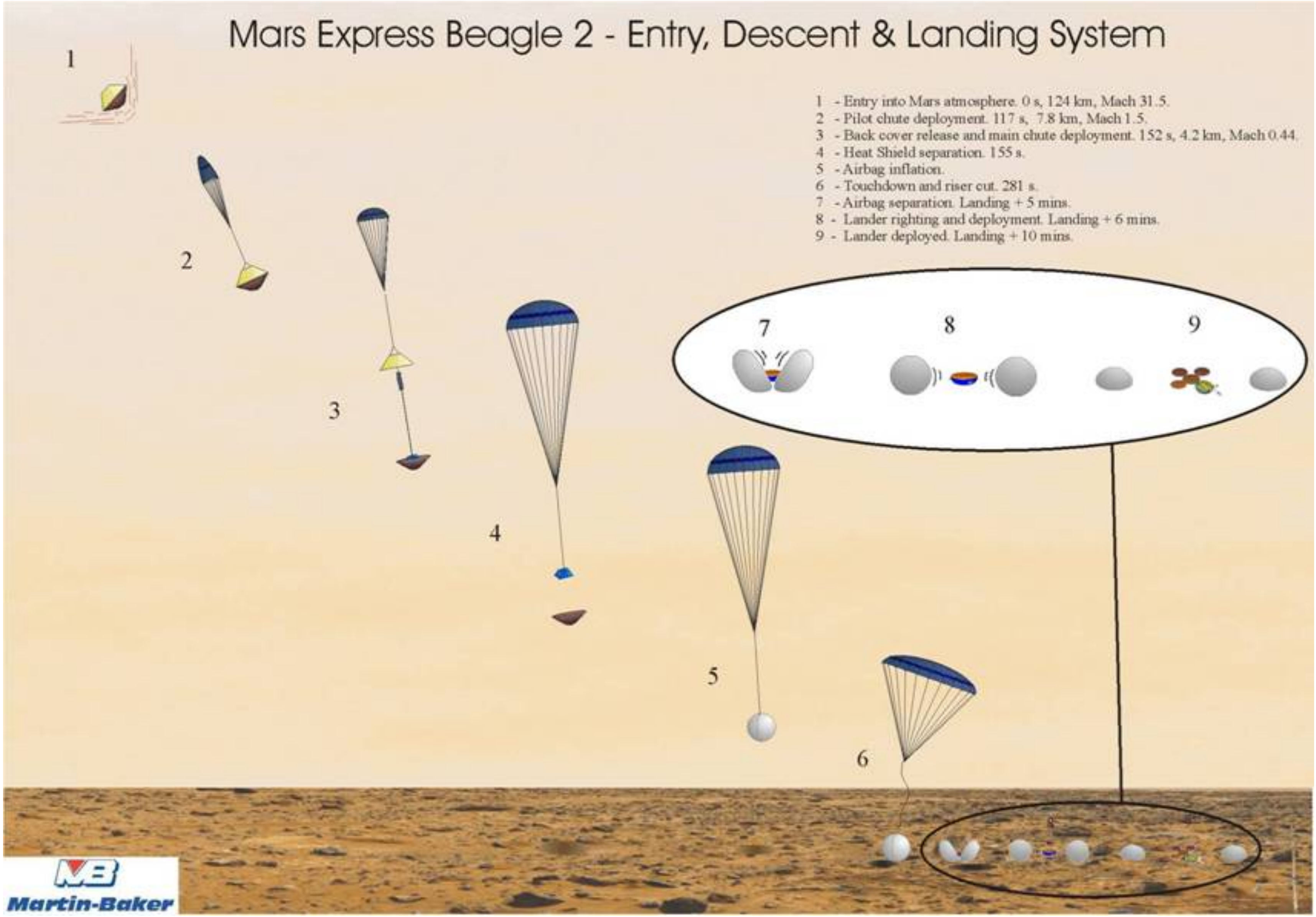


Mars Express



Integration of Beagle 2 multi-layer insulation at the Baikonur Cosmodrome

Landing Sequence



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Lander Boundary Conditions

- Direct and diffuse solar radiation
- Radiative losses to effective sky temperature
- Radiative and conductive losses to surface
- Convective losses to local environment

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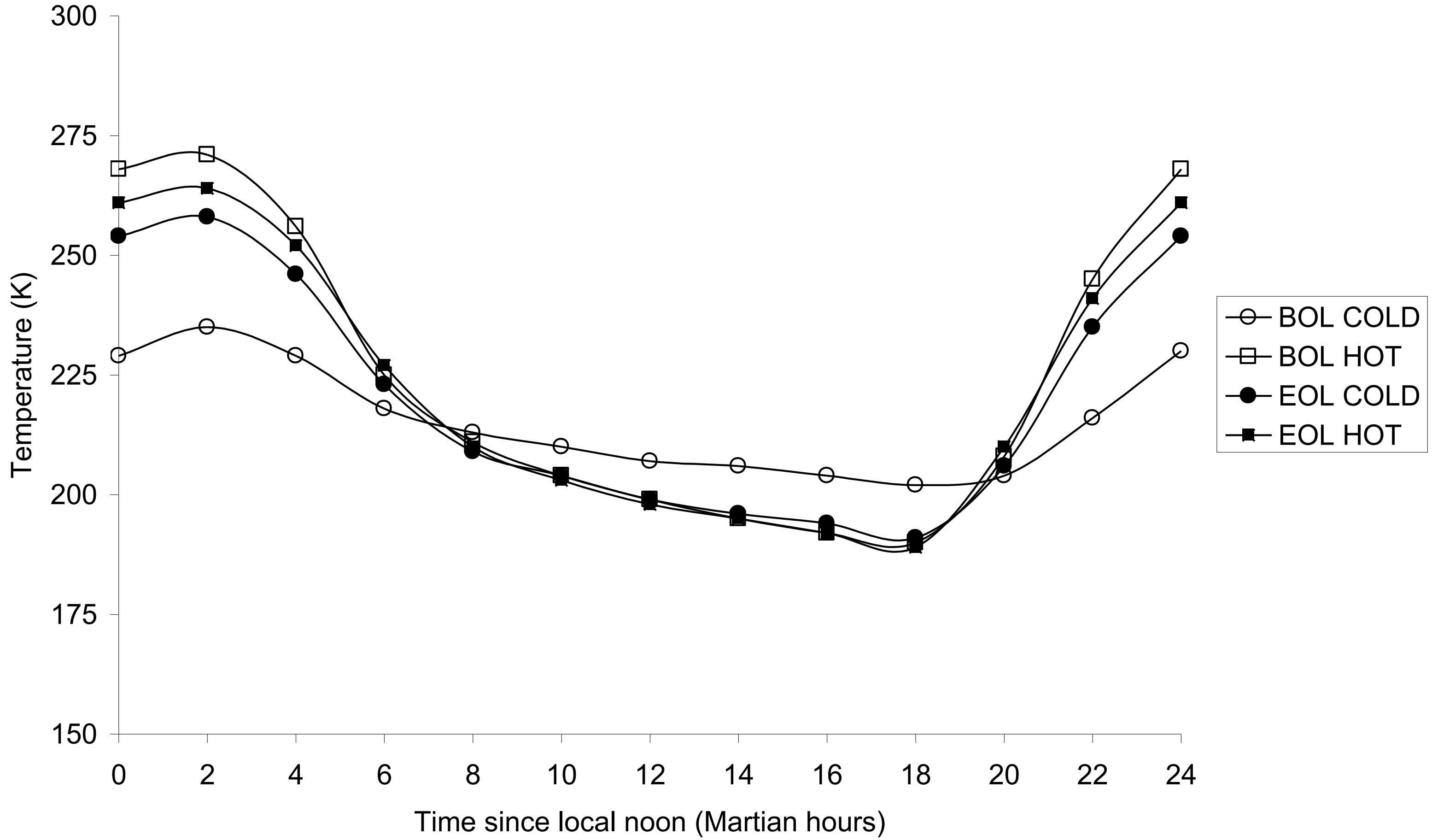
Mars Environment

- Environmental conditions influenced by the level of dust (optical depth) in the atmosphere.
- Time of landing (Ls = 322°) shortly after the dust storm season. Optical depths:
  - Can exceed 5.0 during dust storm
  - 1.0 measured by Viking, decreasing to 0.5 through spring and summer
  - 0.2 measured by Mars Global Surveyor
- Surface temperatures: ~ 0 °C early afternoon to ~ -100 °C just before dawn
- Sky temperature: -100 °C to -150 °C
- Wind speeds typically less than 10 m/s

Environmental Design Cases

	COLD		HOT	
PARAMETER	**BOL**	**EOL**	**BOL**	**EOL**
Aerocentric longitude (°)	322	60	322	60
Latitude (°)	31	31	0	0
Optical depth (-)	2.0	0.7	0.2	0.2
Wind speed (m/s)	10	10	0	0
Interface with surface	'raised'	'raised'	'firm'	'firm'
Dust coverage (%)	-	100	-	24

Mars Environment



Assumed surface temperatures
(taken from Mars Climate Database)

Requirements

- Minimize energy required by survival and operational heaters

- Maintain temperatures within applicable limits:

	NON-OPERATIONAL (°C)		OPERATIONAL (°C)	
UNIT	**MIN**	**MAX**	**MIN**	**MAX**
Battery	-	-	-30	45
Common electronics	-	-	-50	55
Transceiver	-65	55	-65	55
Gas Analysis Package	-65	40	-40	30
Instrument arm	-100	125	-60	30
Solar arrays	-120	-	-	40

Thermal Design Concept

- Thermally isolate battery from structure (low conductance mounts; radiative shielding)
- Thermally couple electronics to battery (~ 8W stand-by dissipation)
- Foam insulation
- Low-emissivity finishes
- Use of survival heaters on battery and elsewhere where necessary
- Qualify components to accommodate wide temperature fluctuations

Preliminary Trade-off (1/2)

- Two approaches were considered for keeping battery warm:
  - Radioisotope heater unit (RHU) coupled to battery
    - 8.5 W dissipation
  - A solar absorber unit (SAU) architecture to optimize absorption of incident solar radiation together with a phase change material (PCM):
    - Tinox solar absorber ($\alpha_s > 0.94$, $\varepsilon < 0.05$)
    - 1.5 kg water PCM

Preliminary Trade-off (2/2)

- Conclusions of trade-off:
  - Both approaches feasible for Lander thermal design
  - RHU approach less sensitive to variations in Lander design parameters, but had narrow design margins in some areas
  - Other technical difficulties with RHUs (e.g., heat rejection system during Cruise/Coast)
  - Conclusion was to focus on development of the SAU approach

Refinement of Design (1/2)

- The use of different solar absorber materials and PCM options was considered.

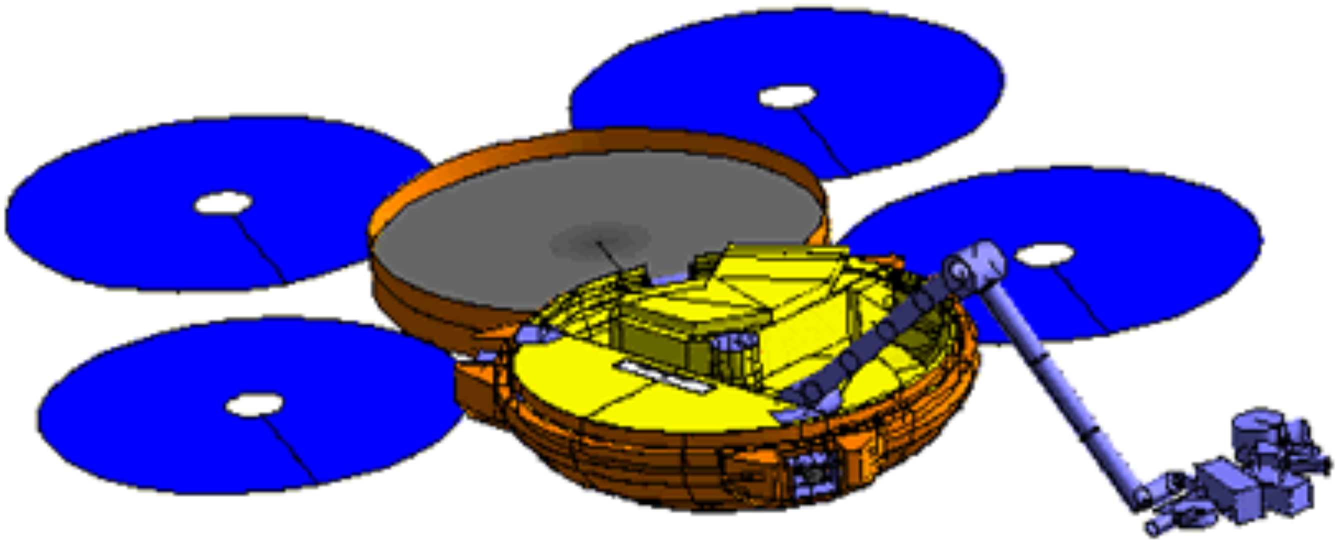
- Solar absorber materials:
  - Tinox ($\alpha_s > 0.94$, $\varepsilon < 0.05$)
  - Germanium x VDA x Kapton ($\alpha_s \sim 0.6$, $\varepsilon \sim 0.05$)
  - Hybrid Tinox/Germanium

- PCM options:
  - None
  - 0.5 kg and 0.86 kg water
  - 0.5 kg and 0.77 kg dodecane wax (melting point ~ - 10 °C)

Refinement of Design (2/2)

- Under cold conditions water PCMs could stay frozen
- A 0.77 kg dodecane PCM had improved response compared with 0.5 kg water, but increased mass was a major concern
- 0.5 kg dodecane PCM was marginal at BOL cold conditions
- Electronics may exceed upper temperatures in hot cases if high-absorptivity (Tinox) absorber used
- A Germanium x VDA x Kapton SAU architecture without a PCM was initially baselined

Detailed Thermal Design



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Detailed Thermal Design

- Low conductance structure (glass-fiber reinforced plastic instead of aluminium honeycomb).
- Inner and outer surfaces of Lander structure gold coated
- Solar absorber finish now gold coated kapton
- Instrument arm wrapped in aluminized tape
- Software controlled heaters on battery, transceiver, and a small number of locations in Lander.

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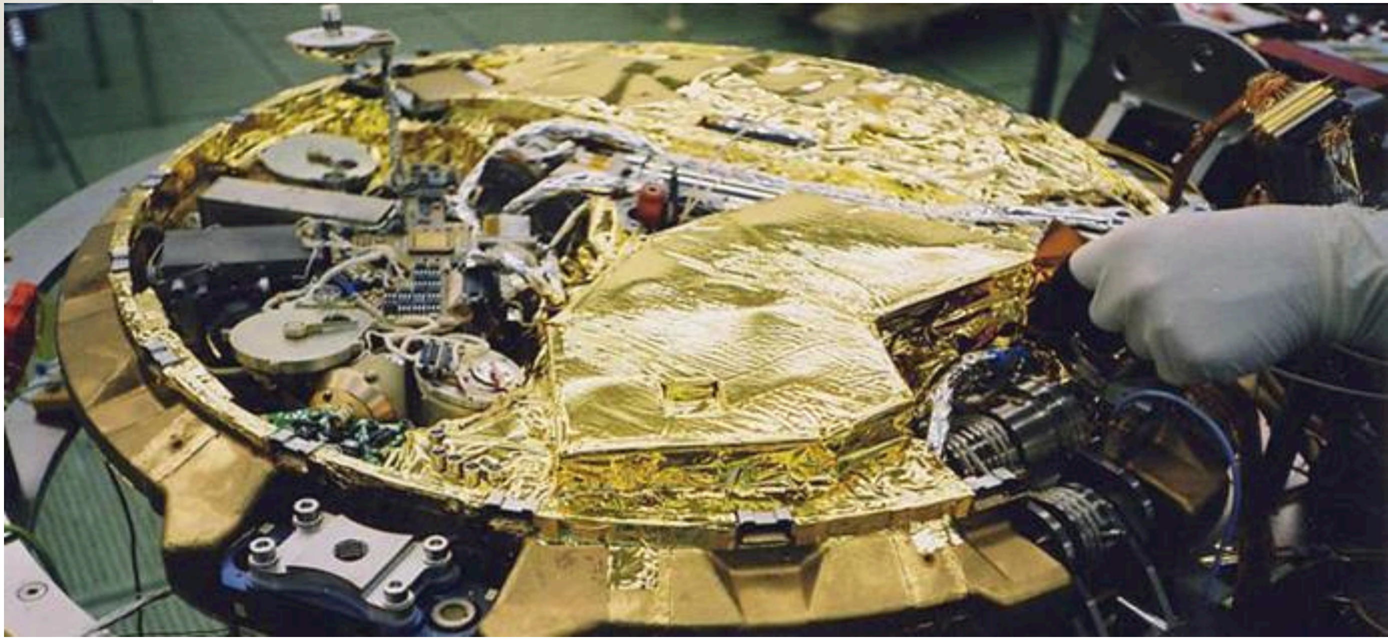
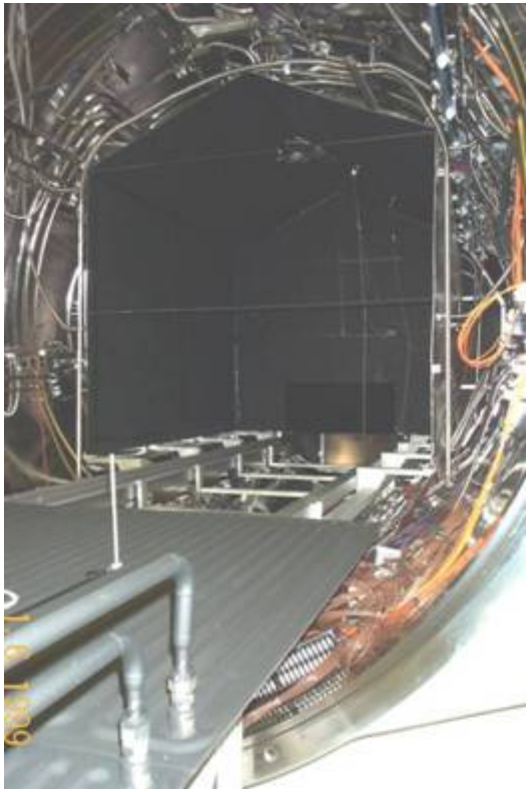
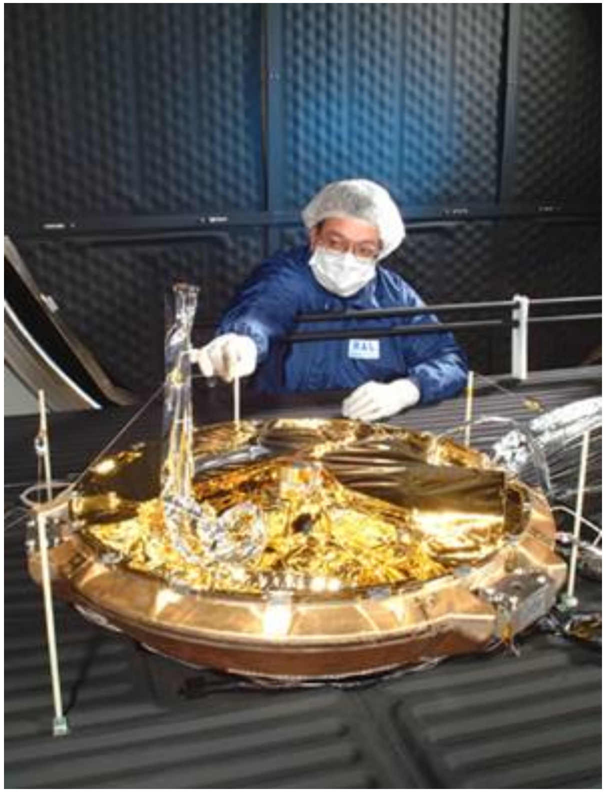
Solar Absorber Unit



Thermal Balance Testing



Lander test shroud



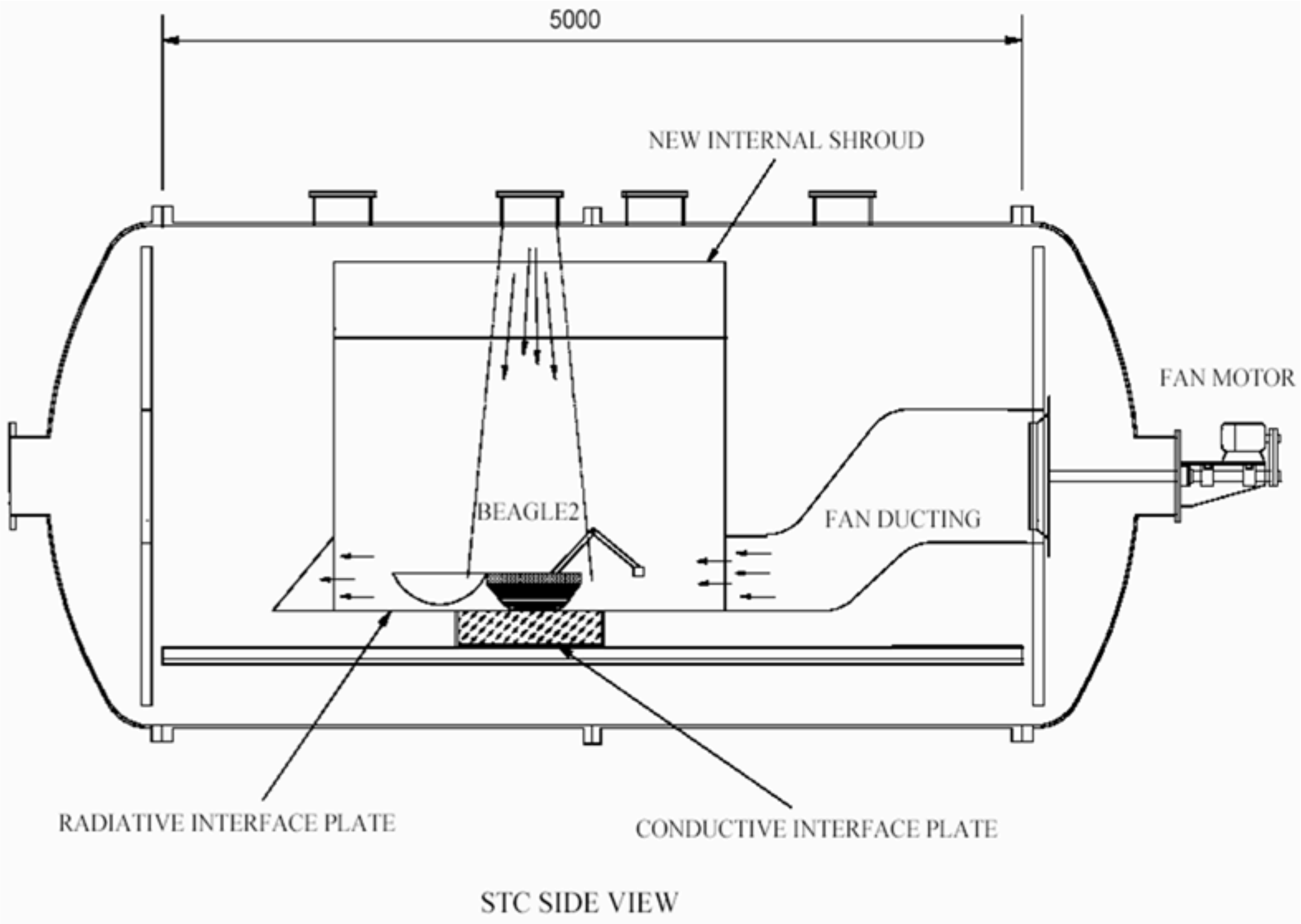
Lander test model,
RAL, May 2002

Probe test model,
RAL, September 2002

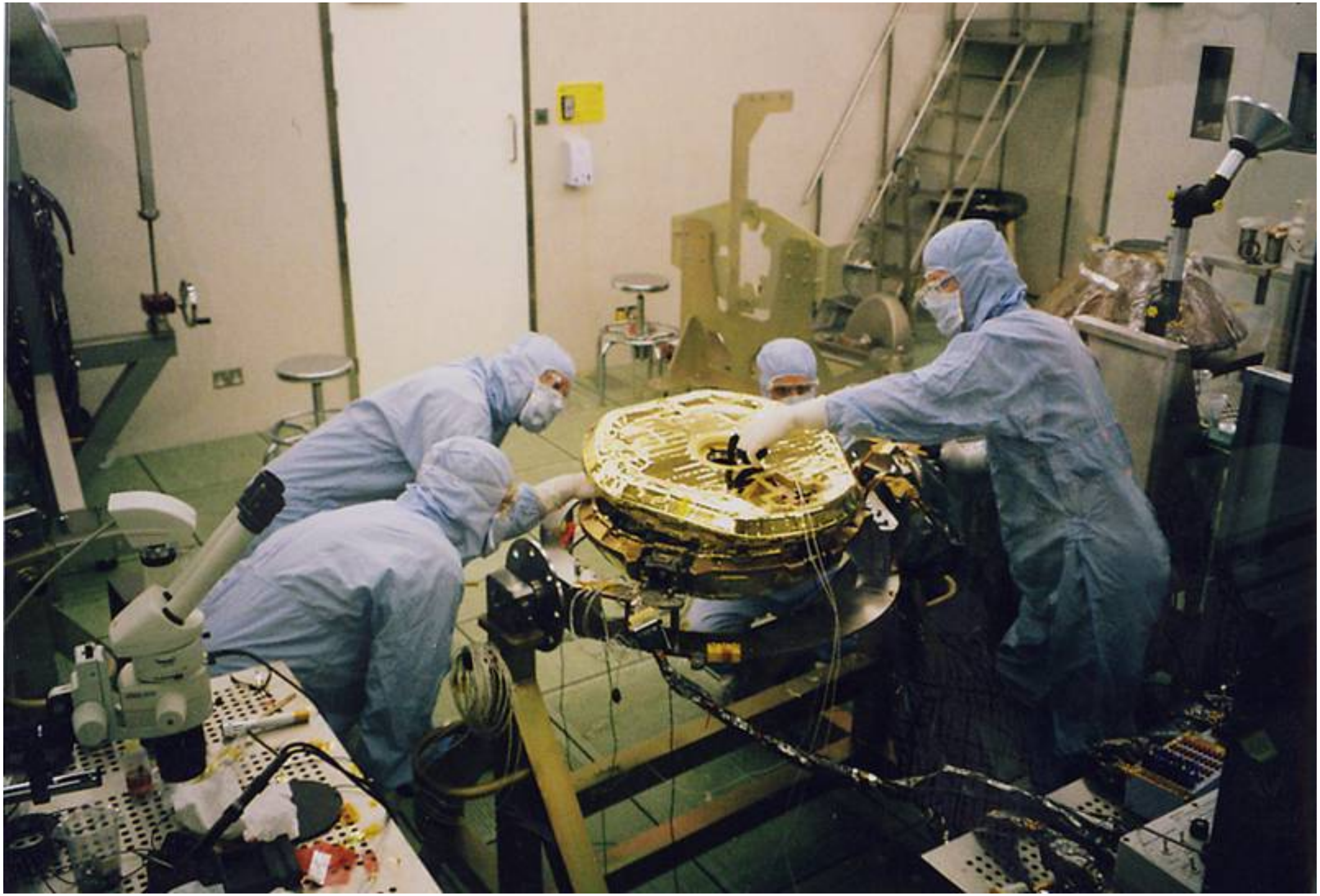
Lander Test Requirements

	Ideal	*Specified*
Lander Model	• Complete	• With lid, but no solar arrays • Partial instrument arm
Surface	• Sandy/rocky – like landing site • Temperature cycling between -100 and 0 °C	• Temperature controlled panels: ○ Beneath Lander ○ Surrounding Martian surface
Atmosphere	• ~ 7 mbar CO_2 • Temperature cycling between -100 and 0 °C • Winds up to 10 m/s	• ~ 7 mbar CO_2 • Temperature not controlled • Winds up to 10 m/s
Sky-view	• -135 °C	• -100 °C
Solar simulator	• Moving beam • 0 – 600 W/m^2 intensity	• Vertically fixed beam • 0 – 600 W/m^2 intensity

Lander Test Implementation



Closing Flight Model Lander



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Conclusions

- Thermal design for the Martian environment is a great challenge
- A thermal design approach which did not require the use of RHUs was developed for Beagle 2
- The thermal design was verified by extensive testing at RAL

Is there life on Mars?