APPENDIX III:
UNIT CONVERSION FACTORS

<table>
<thead>
<tr>
<th>Metric</th>
<th>Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 cm</td>
<td>= 0.3937 in</td>
</tr>
<tr>
<td>1 m</td>
<td>= 3.28084 ft</td>
</tr>
<tr>
<td>1 m²</td>
<td>= 10.764 ft²</td>
</tr>
<tr>
<td>1 km/s</td>
<td>= 3280.8 ft/s</td>
</tr>
<tr>
<td>1 kg</td>
<td>= 2.20462 lb</td>
</tr>
<tr>
<td>1 kg/m²</td>
<td>= 0.2048 lb/ft²</td>
</tr>
<tr>
<td>1 kg/m³</td>
<td>= 0.06243 lb/ft³</td>
</tr>
<tr>
<td>1 Joule</td>
<td>= 0.9478x10⁻³ BTU</td>
</tr>
</tbody>
</table>

1 Watt = 1 J/s = 0.9478x10⁻³ BTU/s

1 J/cm² = 0.88055 BTU/ft²

1 W/cm² = 0.88055 BTU/ft².s

1 atm = 1.01325x10³ Pa

Due to the changing nature of planetary vehicles during the design, manufacture and mission phases, and to the variables involved in measurement and computation, please be aware that the data provided herein cannot be guaranteed. Contact Carol Davies at cdavies@mail.arc.nasa.gov to correct or update the current data, or to suggest other missions. All contacts are welcome.
DEFINITIONS
CONTINUED

Trim L/D
The L/D where vehicle is statically stable. The vehicle will trim (restore) to trim angle of attack if variations occur.

Ballistic coefficient
The ratio of the product of drag coefficient (C) and projected reference area (A) to mass (m), giving m/C/A.

Stagnation heating rate
The maximum convective heat flux at the stagnation point. Depends on trajectory. The stagnation point is where the velocity to the surface adiabatically comes to zero. Location depends on angle of attack and deviation behind the shock. The stagnation point is often where the maximum heating rate occurs, but not always.

Integrated heat load
The convective heat flux integrated over flight time. The highest heat load is usually, but not always, at the stagnation point. The integrated heat load will vary over the vehicle surface.

Radiative heat flux at stagnation point
This is the heat flux radiated from the shock layer to the surface. It may or may not be a maximum at the stagnation point.

Peak heat stagnation pressure
The pressure at the time of maximum convective heat flux. This is not the peak pressure, which occurs later in the trajectory.

Material designation
This can be a material trade name, defined by the manufacturer (e.g., SLA-561V) or a generic designator applied to a class of materials (e.g., carbon phenolic). It provides little useful information about the material other than a broad description of its constituents.

Thickness
This is “as manufactured” thickness of the material, usually specified at the stagnation point. Useful for a TPS of uniform thickness; less useful for a “tailored” TPS. The “as manufactured” thickness includes the “nominal design thickness” to which additional thickness is added (margin) to accommodate uncertainties in the entry environment and/or material performance.

Resin material
This is the “organic matrix” (e.g., epoxy, silicone, phenolic) in an organic matrix composite wherein the matrix (glue) fills the voids and provides rigidity to the structural reinforcement (e.g., fibers, fabric, honeycomb). The organic resin will pyrolyze when heated, typically leaving a carbonaceous residue (char).

Matrix material
Analogous to a resin material in primary function, the matrix is typically stable and will not pyrolyze when heated. Examples include inorganic ceramics (e.g., glass, alumina) in ceramic matrix composites and carbon in carbon-carbon composites.
APPENDIX II: DEFINITIONS

Entry angle, $\gamma$
The angle between the local horizontal plane (orthogonal to the vector from the planet center to the vehicle) and the velocity vector of the vehicle, $V$, at a reference altitude, $h$. The entry angle can be inertial or relative, depending on entry velocity used. $\gamma$ is negative when $V$ is below the horizontal plane, as in planetary entry.

Inertial entry velocity
The vehicle velocity at reference altitude, $h$, assuming a non-rotating planet.

Relative entry velocity
The inertial entry velocity amended by the component of the planet's rotation, assuming the atmosphere to be a solid body.

Velocity at peak heat
The velocity when the vehicle reaches the maximum convective heat flux at the stagnation point.

Control method
(a) Ballistic: no control, subject to drag forces only, with passive stability about zero lift condition;
(b) Controlled Ballistic: active control to maintain zero lift; and
(c) RCS: a set of small engines called the reaction control system (RCS) engines.

Center of gravity
In the table, the value of $X_{CG}/D$ is given, where $D$ is the maximum diameter of the vehicle. On the diagram, the actual $X_{CG}$ is shown. Most CG are not exactly on the centerline because of manufacturing tolerances, but generally the $Y$ value wasn’t given or it is so close that it doesn’t show up in the diagram. The exceptions were Apollo command modules and the Viking landers, where the $Y$ offset was deliberate to achieve the desired angles of attack.

Shape
All vehicles are spherically blunted cones, or spherical, or conical.

Nose radius
The radius of the spherical nose, or the capsule radius.

Base area
The base area projected along the centerline.

Vehicle mass
The total vehicle mass of the vehicle at entry, including TPS and payload. Generally, the vehicle mass at entry is the same as take-off mass minus any fuel used for maneuvering. However, the mass can change after leaving the orbiter but before entry. An example is the small probe of Pioneer Venus where the spin yo-yo was jettisoned before entry. The mass can also change during entry if the heat shield material ablates. An (extreme) example was the Galileo probe that lost about 26% of its entry mass to ablation.

TPS mass fraction
The proportion of TPS mass to vehicle mass at entry. Insulator may or may not be included.

Payload mass
The proportion of payload mass (scientific instruments and may include transmitters, batteries etc.) to vehicle mass.
MISSION: FIRE II  
PLANET: EARTH

LAUNCH: MAY 22, 1965
ENTRY: MAY 22, 1965

MISSION DESCRIPTION:  
Technology demonstrator for Apollo re-entry heating environment

INSTRUMENTATION:
- Three forebody calorimeters, 11 forebody thermocouples, 12 offset radiometer thermocouples and one static pressure transformer on the afterbody
- Data Collected by: M. J. Wright

NOTES:
- This aero thermal flight test was to evaluate radiative heating for Apollo.
- The reentry package consisted of three separate heat shield/calorimeter combinations, therefore the mass and OML changed with time.

REFERENCES:
MISSION: APOLLO AS-201
PLANET: EARTH

LAUNCH: Feb 26, 1966
ENTRY: Feb 26, 1966

MISSION DESCRIPTION:
First unmanned suborbital flight to test the Saturn 1B launch vehicle, and the command and service modules

INSTRUMENTATION:
- 36 pressure sensors all worked OK, 35 calorimeters worked initially

NOTES:
- TPS thickness: Ablator = 4.32 cm, braised stainless steel substructure (PH 15-7 MO) = 5.08 cm
- Insulation: (TG-15,000) = 2.03 cm, aluminum honeycomb (2014-T6 and 5052-H39) = 3.81 cm
- Peak heating is not at stagnation point
- Manufacturer: AVCO Corp

REFERENCES:

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<thead>
<tr>
<th>Trajectory</th>
<th>Geometry</th>
<th>Aero/thermal</th>
<th>TPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry angle</td>
<td>-8.58° inertial, -9.03° relative</td>
<td>Shape</td>
<td>Capsule: 33° cone</td>
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<tr>
<td>Inertial entry velocity</td>
<td></td>
<td>Nose radius</td>
<td>4.69 m, 3 m effective</td>
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<tr>
<td>Relative entry velocity</td>
<td>7.67 km/s</td>
<td>Base area</td>
<td>12.02 m²</td>
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<tr>
<td>Velocity at peak heat</td>
<td>5.73 km/s</td>
<td>Vehicle mass</td>
<td></td>
</tr>
<tr>
<td>Control method</td>
<td>No control: Rolled</td>
<td>TPS mass fraction, incl. insul.</td>
<td>13.7%</td>
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<tr>
<td>Center of Gravity, $X_{CG}/D$</td>
<td>.27</td>
<td>Payload mass</td>
<td>None</td>
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<tr>
<td>PH stag. pressure</td>
<td>0.85 atm</td>
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<td></td>
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<tr>
<td>Total material density</td>
<td>Ablator: 544.6 kg/m³</td>
<td></td>
<td></td>
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</table>

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MANNED MISSIONS
United States

Mercury Program:
12/19/60 MR-1
01/31/61 MR-2
02/21/61 MA-2
05/03/61 MR-3 (Freedom 7)
07/21/61 MR-4 (Liberty Bell 7)
09/13/61 MA-4
11/29/61 MA-5
02/20/62 MA-6 (Friendship 7)
05/24/62 MA-7 (Aurora 7)
10/03/62 MA-8 (Sigma 7)

Suborbital flight
Orbital test
Suborbital flight
Orbital test
Chimp “Enos”
Earth orbit
Earth orbit
Earth orbit

Data Collected by: C. Park and M.J. Wright
### Unmanned Planetary Probes  
Soviet Union/Russia continued

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<thead>
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<th>Spacecraft</th>
<th>Target</th>
<th>Remarks</th>
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<td>02/12/61</td>
<td>Venera 1</td>
<td>Venus</td>
<td>Venus flyby (communications failure)</td>
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<td>11/12/65</td>
<td>Venera 2</td>
<td>Venus</td>
<td>Venus flyby (communications failure)</td>
</tr>
<tr>
<td>11/16/65</td>
<td>Venera 3</td>
<td>Venus</td>
<td>Venus impact (3/1/66 - comm. failure)</td>
</tr>
<tr>
<td>06/12/67</td>
<td>Venera 4</td>
<td>Venus</td>
<td>Venus atmospheric entry (10/18/67)</td>
</tr>
<tr>
<td>01/05/69</td>
<td>Venera 5</td>
<td>Venus</td>
<td>Venus atmospheric entry (5/16/69)</td>
</tr>
<tr>
<td>01/10/69</td>
<td>Venera 6</td>
<td>Venus</td>
<td>Venus atmospheric entry (5/17/69)</td>
</tr>
<tr>
<td>08/17/70</td>
<td>Venera 7</td>
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<td>Venus landing (12/5/70)</td>
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<td>03/27/72</td>
<td>Venera 8</td>
<td>Venus</td>
<td>Venus landing (7/22/72)</td>
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<td>06/08/75</td>
<td>Venera 9</td>
<td>Venus</td>
<td>Venus orbit &amp; landing (10/22/75)</td>
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<td>06/14/75</td>
<td>Venera 10</td>
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<td>Venus orbit &amp; landing (10/25/75)</td>
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<td>09/09/78</td>
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<td>Venus flyby &amp; landing (12/25/78)</td>
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<td>Venus</td>
<td>Venus flyby &amp; landing (12/21/78)</td>
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<td>Venus</td>
<td>Venus flyby &amp; landing (3/1/82)</td>
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<td>11/04/81</td>
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<td>Venus flyby &amp; landing (3/5/82)</td>
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<td>06/02/83</td>
<td>Venera 15</td>
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<td>Venus orbit radar mapper (10/10/83)</td>
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<tr>
<td>06/07/83</td>
<td>Venera 16</td>
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<td>Venus orbit radar mapper (10/14/83)</td>
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<td>11/01/82</td>
<td>Mars 1</td>
<td>Mars</td>
<td>Mars flyby (communications failure)</td>
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<td>05/19/71</td>
<td>Mars 2</td>
<td>Mars</td>
<td>Mars orbiter/lander crashed (11/26/71)</td>
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<tr>
<td>05/28/71</td>
<td>Mars 3</td>
<td>Mars</td>
<td>Mars orbiter/lander crashed (12/3/71)</td>
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<td>07/21/73</td>
<td>Mars 4</td>
<td>Mars</td>
<td>Mars orbiter missed (2/10/74)</td>
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<td>Mars orbit (2/12/74)</td>
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<td>08/05/73</td>
<td>Mars 6</td>
<td>Mars</td>
<td>Crashed on Mars (3/12/74)</td>
</tr>
<tr>
<td>08/09/73</td>
<td>Mars 7</td>
<td>Mars</td>
<td>Mars lander missed (9/9/74)</td>
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<td>04/02/64</td>
<td>Zond 1</td>
<td>Venus</td>
<td>Venus flyby (communications failure)</td>
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<td>11/30/66</td>
<td>Zond 2</td>
<td>Mars</td>
<td>Mars flyby (communications failure)</td>
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<tr>
<td>07/18/65</td>
<td>Zond 3</td>
<td>Moon</td>
<td>Lunar flyby (pre-manned test)</td>
</tr>
<tr>
<td>03/02/68</td>
<td>Zond 4</td>
<td>Moon</td>
<td>Circumlunar failure (pre-manned test)</td>
</tr>
<tr>
<td>09/15/68</td>
<td>Zond 5</td>
<td>Moon</td>
<td>Circumlunar (pre-manned test)</td>
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<tr>
<td>11/10/68</td>
<td>Zond 6</td>
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</tr>
<tr>
<td>08/08/69</td>
<td>Zond 7</td>
<td>Moon</td>
<td>Circumlunar (pre-manned test)</td>
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<td>10/20/70</td>
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<tr>
<td>12/15/84</td>
<td>Vega 1</td>
<td>Venus</td>
<td>Venus flyby &amp; landing (6/11/85)</td>
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<tr>
<td>12/21/84</td>
<td>Vega 2</td>
<td>Comet</td>
<td>Halley flyby (3/6/86 - 5,500 mi.)</td>
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<tr>
<td>07/07/88</td>
<td>Phobos 1</td>
<td>Mars</td>
<td>Phobos/Mars orbit (comm. failure)</td>
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<tr>
<td>07/12/88</td>
<td>Phobos 2</td>
<td>Mars</td>
<td>Phobos/Mars orbit (comm. failure)</td>
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<tr>
<td>11/16/96</td>
<td>Mars 96</td>
<td>Mars</td>
<td>2 Mars landers (launch failure)</td>
</tr>
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</table>

**Mission:** APOLLO AS-202  
**Planet:** EARTH

**Launch:** Aug 25, 1966  
**Entry:** Aug 25, 1966

**Mission Description:** Second unmanned suborbital flight to test the Saturn 1B launch vehicle, and the command and service modules.

**Data Collected by:** C. Park

**Instrumentation:**
- 36 pressure sensors all worked OK, 35 calorimeters worked initially

**Notes:**
- TPS thickness: Ablator = 4.32 cm, braised stainless steel substructure (PH 15-7 MO) = 5.08 cm
- Insulation: (TG-15,000) = 2.03 cm, aluminum honeycomb (2014-T6 and 5052-H39) = 3.81 cm
- Manufacturer: AVCO Corp

**References:**
MISSION: APOLLO 4
PLANET: EARTH

LAUNCH: Nov 9, 1967
ENTRY: Nov 9, 1967

MISSION DESCRIPTION: Test of Saturn V launch vehicle and overall re-entry operations

MISSION DATA:

Data Collected by: C. Park

INSTRUMENTATION:
- 17 pressure sensors all worked and 23 calorimeters worked initially. Radiometer functioned well.

NOTES:
- TPS thickness: Ablator = 4.32 cm, braised stainless steel substructure (PH 15-7 MO) = 5.08 cm
- Insulation: (TG-15,000) = 2.03 cm, aluminum honeycomb (2014-T6 and 5052-H39) = 3.81 cm
- Manufacturer: AVCO Corp

REFERENCES:
**MISSION:** APOLLO 6  
**PLANET:** EARTH  
**LAUNCH:** Apr 4, 1968  
**ENTRY:** Apr 4, 1968  
**MISSION DESCRIPTION:** Final qualification test for launch vehicle and command module for manned mission  

**INSTRUMENTATION:**  
- TPS thickness: Ablator = 4.32 cm, braised stainless steel substructure (PH 15-7 MO) = 5.08 cm  
- Insulation: (TG-15,000) = 2.03 cm, aluminum honeycomb (2014-T6 and 5052-H39) = 3.81 cm  
- Manufacturer: AVCO Corp  

**REFERENCES:**  

### Data Collected by: C. Park

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<thead>
<tr>
<th>Date</th>
<th>Spacecraft</th>
<th>Target</th>
<th>Remarks</th>
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</thead>
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<td>08/20/75</td>
<td>Viking 1</td>
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<td>Mars orbit &amp; landing (7/20/76)</td>
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<td>Mars orbit &amp; landing (9/3/76)</td>
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<td>ICE (ISEE-3)</td>
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<td>Solar orbit</td>
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<td>Comet Giacobini-Zinner flyby (9/11/85)</td>
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<td>Jupiter</td>
<td>Jupiter flyby (3/5/79 - 174,000 mi.)</td>
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<td>Saturn flyby (11/12/80 - 77,000 mi.)</td>
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<td>Jupiter</td>
<td>Jupiter flyby (7/9/79 - 400,000 mi.)</td>
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<td>Venus orbit radar mapper (12/4/78)</td>
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<td>Galileo</td>
<td>Venus</td>
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<td>Flyby (8/28/93 - 2,400 mi.)</td>
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<td>Shoemaker NEAR</td>
<td>Asteroid Mathilde Flyby (6/27/97)</td>
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<td>Asteroid Eros</td>
<td>Flyby (12/23/98)</td>
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<td>Orbit (10/26/00)</td>
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<td>Mars orbit (9/11/97)</td>
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<td>Earth flyby (8/17/99 - 727 mi.)</td>
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<td>Saturn</td>
<td>Saturn orbit (6/3/04)</td>
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<td></td>
<td>Titan</td>
<td>Carried ESA’s Huygens probe</td>
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<td>Touchdown (1/14/05)</td>
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<td>Lunar Prospector</td>
<td>Moon</td>
<td>Lunar orbital mapper</td>
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**REFERENCES:**

### APPENDIX I

**LIST OF SPACE VEHICLES AND THEIR MISSIONS**

#### Unmanned Planetary Probes

**United States**

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<thead>
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<th>Date</th>
<th>Spacecraft</th>
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<th>Remarks</th>
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<td>Lunar flyby</td>
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<td>Solar orbit</td>
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<td>Pioneer 8</td>
<td>Sun</td>
<td>Solar orbit</td>
</tr>
<tr>
<td>11/08/68</td>
<td>Pioneer 9</td>
<td>Sun</td>
<td>Solar orbit</td>
</tr>
<tr>
<td>03/03/72</td>
<td>Pioneer 10</td>
<td>Jupiter</td>
<td>Jupiter flyby (12/3/73 - 81,000 mi.)</td>
</tr>
<tr>
<td>04/05/73</td>
<td>Pioneer 11</td>
<td>Jupiter</td>
<td>Jupiter flyby (12/2/74 - 26,600 mi.)</td>
</tr>
<tr>
<td>01/26/62</td>
<td>Ranger 3</td>
<td>Moon</td>
<td>Lunar flyby</td>
</tr>
<tr>
<td>04/23/62</td>
<td>Ranger 4</td>
<td>Moon</td>
<td>Lunar impact</td>
</tr>
<tr>
<td>10/10/62</td>
<td>Ranger 5</td>
<td>Moon</td>
<td>Lunar flyby</td>
</tr>
<tr>
<td>01/30/64</td>
<td>Ranger 6</td>
<td>Moon</td>
<td>Lunar impact</td>
</tr>
<tr>
<td>07/28/64</td>
<td>Ranger 7</td>
<td>Moon</td>
<td>Lunar impact/photos</td>
</tr>
<tr>
<td>02/17/65</td>
<td>Ranger 8</td>
<td>Moon</td>
<td>Lunar impact/photos</td>
</tr>
<tr>
<td>03/21/65</td>
<td>Ranger 9</td>
<td>Moon</td>
<td>Lunar impact/photos</td>
</tr>
<tr>
<td>08/26/62</td>
<td>Mariner 2</td>
<td>Venus</td>
<td>Venus flyby (12/14/65 - 22,000 mi.)</td>
</tr>
<tr>
<td>11/05/64</td>
<td>Mariner 3</td>
<td>Mars</td>
<td>Mars flyby (comm. failure)</td>
</tr>
<tr>
<td>11/28/64</td>
<td>Mariner 4</td>
<td>Mars</td>
<td>Mars flyby (7/14/65 - 6,100 mi.)</td>
</tr>
<tr>
<td>06/14/67</td>
<td>Mariner 5</td>
<td>Venus</td>
<td>Venus flyby (10/19/67 - 2,500 mi.)</td>
</tr>
<tr>
<td>02/25/69</td>
<td>Mariner 6</td>
<td>Mars</td>
<td>Mars flyby (7/31/69 - 2,100 mi.)</td>
</tr>
<tr>
<td>03/27/69</td>
<td>Mariner 7</td>
<td>Mars</td>
<td>Mars flyby (8/5/69 - 2,200 mi.)</td>
</tr>
<tr>
<td>05/30/71</td>
<td>Mariner 9</td>
<td>Mars</td>
<td>Mars orbit (11/13/71)</td>
</tr>
<tr>
<td>11/02/73</td>
<td>Mariner 10</td>
<td>Venus</td>
<td>Venus flyby (2/5/74 - 3,600 mi.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mercury</td>
<td>Mercury flyby (3/29/74 - 460 mi.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mercury</td>
<td>Mercury flyby (9/21/74 - 30,000 mi.)</td>
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<tr>
<td></td>
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<td>Mercury</td>
<td>Mercury flyby (3/16/75 - 200 mi.)</td>
</tr>
<tr>
<td>06/30/66</td>
<td>Surveyor 1</td>
<td>Moon</td>
<td>Lunar landing</td>
</tr>
<tr>
<td>09/20/66</td>
<td>Surveyor 2</td>
<td>Moon</td>
<td>Crashed on the Moon</td>
</tr>
<tr>
<td>04/17/67</td>
<td>Surveyor 3</td>
<td>Moon</td>
<td>Lunar landing</td>
</tr>
<tr>
<td>07/14/67</td>
<td>Surveyor 4</td>
<td>Moon</td>
<td>Crashed on the Moon</td>
</tr>
<tr>
<td>09/08/67</td>
<td>Surveyor 5</td>
<td>Moon</td>
<td>Lunar landing</td>
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<tr>
<td>11/07/67</td>
<td>Surveyor 6</td>
<td>Moon</td>
<td>Lunar landing</td>
</tr>
<tr>
<td>01/07/68</td>
<td>Surveyor 7</td>
<td>Moon</td>
<td>Lunar landing</td>
</tr>
<tr>
<td>08/10/66</td>
<td>Lunar Orbiter 1</td>
<td>Moon</td>
<td>Lunar orbit</td>
</tr>
<tr>
<td>11/06/66</td>
<td>Lunar Orbiter 2</td>
<td>Moon</td>
<td>Lunar orbit</td>
</tr>
<tr>
<td>02/04/67</td>
<td>Lunar Orbiter 3</td>
<td>Moon</td>
<td>Lunar orbit</td>
</tr>
<tr>
<td>05/04/67</td>
<td>Lunar Orbiter 4</td>
<td>Moon</td>
<td>Lunar orbit</td>
</tr>
<tr>
<td>08/01/67</td>
<td>Lunar Orbiter 5</td>
<td>Moon</td>
<td>Lunar orbit</td>
</tr>
</tbody>
</table>

**INSTRUMENTATION:**

- Multiple thermocouples and pressure sensors at 21 stations on cone, 4 heat-flux gauges and 2 pressure gauges on base.
- 3 thermocouples in nose-tip assembly

**NOTES:**

- Nose-tip heating rate is not relevant for this flight, which was designed to measure heating on a sharp cone.
- The nose tip was meant to ablate during entry.
- The beryllium heat shield melted about 40 seconds after entry.

**REFERENCES:**


Data Collected by: M.J. Wright and G. Allen
MISSION: **PAET**  
PLANET: **EARTH**  
**LAUNCH:** June 2, 1971  
**ENTRY:** June 2, 1971  

**MISSION DESCRIPTION:**
To test the capability to determine the composition of unknown atmospheres during high-speed entry.

---

**INSTRUMENTATION:**
- Forebody: 2 beryllium heat transfer gauges, 2 heat shield plugs in the ablator and pressure gauge in beryllium cap.
- Afterbody: Thermocouple in low-density ablator (SLA-220) located slightly aft of shoulder.

**NOTES:**
- Nose: Beryllium heatsink
- Conical frustrum: ESA 3560 ablator

---

**REFERENCES:**

---

**Data Collected by:** M. Tauber
**MISSION: VIKING LANDER 1**  
**PLANET: MARS**  
**LAUNCH:** AUG 20, 1975  
**ENTRY:** JUL 20, 1976  

**Mission Description:**
To characterize the structure and composition of the atmosphere and surface of Mars

<table>
<thead>
<tr>
<th>Trajectory</th>
<th>Geometry</th>
<th>Aero/thermal</th>
<th>TPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry angle</td>
<td>Inertial -16.99°</td>
<td>Shape</td>
<td>70° sphere-cone</td>
</tr>
<tr>
<td>Inertial entry velocity</td>
<td>4.61 km/s</td>
<td>Nose radius</td>
<td>0.88 m</td>
</tr>
<tr>
<td>Relative entry velocity</td>
<td>4.42 km/s</td>
<td>Base area</td>
<td>9.65 m²</td>
</tr>
<tr>
<td>Velocity at peak heat</td>
<td>4.02 km/s</td>
<td>Vehicle mass</td>
<td>980 kg</td>
</tr>
<tr>
<td>Control method, e.g. flag deflec.</td>
<td>3-axis RCS</td>
<td>TPS mass fraction, inc. insul.</td>
<td>2.8%</td>
</tr>
<tr>
<td>Center of Gravity, Xc/D</td>
<td>0.219 (Ref. 3)</td>
<td>Payload mass</td>
<td>PH stag. Pressure</td>
</tr>
</tbody>
</table>

**INSTRUMENTATION:**
- The forebody aeroshell was not instrumented, but the wake enclosure (backshell) had thermocouples.
- There was one pressure port off stagnation point and one on the base cover.
- Temperature gauges were on the back face and on both back-shell frustums.

**NOTES:**
- Resin Material: silicone elastomer with glass microspheres and cork
- Matrix material: fiberglass-phenolic honeycomb
- RCS was used to maintain trim angle of attack

**REFERENCES:**

---

**MISSION: MARS EXPLORATION ROVERS**  
**“Spirit” and “Opportunity”**  
**PLANET: MARS**  
**LAUNCH:** JUN 10, 2003 & JUL 7, 2003  
**ENTRY:** JAN 3, 2004 & JAN 24, 2004  

**Mission Description:**
To place two rovers (A and B) on Mars to conduct remote geological investigations including search for past water activity

<table>
<thead>
<tr>
<th>Trajectory</th>
<th>Geometry</th>
<th>Aero/thermal</th>
<th>TPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry angle</td>
<td>-11.5° @ 125 km</td>
<td>Shape</td>
<td>70° sphere-cone</td>
</tr>
<tr>
<td>Inertial entry velocity</td>
<td>Nose radius</td>
<td>0.66 m</td>
<td>Ballistic coeff.</td>
</tr>
<tr>
<td>Relative entry velocity</td>
<td>5.55 km/s</td>
<td>Base area</td>
<td>5.52 m²</td>
</tr>
<tr>
<td>Velocity at peak heat</td>
<td>4.93 km/s</td>
<td>Vehicle mass</td>
<td>836 kg</td>
</tr>
<tr>
<td>Control method</td>
<td>Ballistic</td>
<td>TPS mass fraction, inc. insul.</td>
<td>3.6%</td>
</tr>
<tr>
<td>Center of Gravity, Xc/D</td>
<td>0.30</td>
<td>Payload mass</td>
<td>PH stag. pressure</td>
</tr>
</tbody>
</table>

**INSTRUMENTATION:**
- MER A and MER B are two separate missions, each carrying a rover to Mars. Data here are for MER B, the most severe entry environment.
- This mission uses an entry aeroshell similar to that of Pathfinder, however the enclosed rovers are larger than Sojourner and are self-contained.
- There are 3 TIRS (Transverse Impulse Rocket System) covers made of SIRCA spaced around the backshell.

**NOTES:**
- MER A and MER B are two separate missions, each carrying a rover to Mars. Data here are for MER B, the most severe entry environment.
- This mission uses an entry aeroshell similar to that of Pathfinder, however the enclosed rovers are larger than Sojourner and are self-contained.
- There are 3 TIRS (Transverse Impulse Rocket System) covers made of SIRCA spaced around the backshell.

**REFERENCES:**
**MISSION: BEAGLE 2**

**PLANET:** MARS

**LAUNCH:** Jun 2, 2003

**ENTRY:** Dec 25, 2003

**MISSION DESCRIPTION:**
To develop a low-cost low-mass system for placing an exobiology science payload on Mars.

**INSTRUMENTATION:**
- No TPS instrumentation: axial accelerometers only.

**NOTES:**
- Image (all rights reserved Beagle 2) is an impression of Beagle 2 post separation from Mars Express.
- Beagle 2 landed on Mars but did not make radio contact.

**REFERENCES:**
7. Data Collected by: A. Smith.

**MISSION: VIKING LANDER 2**

**PLANET:** MARS

**LAUNCH:** Sep 9, 1975

**ENTRY:** Sep 3, 1976

**MISSION DESCRIPTION:**
To characterize the structure and composition of the atmosphere and surface of Mars.

**INSTRUMENTATION:**
- No TPS instrumentation: axial accelerometers only.

**NOTES:**
- Resin Material: silicone elastomer with glass microspheres and cork.
- Matric material: fiberglass-phenolic honeycomb.
- RCS was used to maintain trim angle of attack.

**REFERENCES:**
5. Data Collected by: A. Smith.
MISSION: PIONEER-VENUS  
SMALL "NORTH PROBE"  
PLANET: VENUS  
LAUNCH: Aug 8, 1978  
ENTRY: Dec 9, 1978  
MISSION DESCRIPTION:  
A 60° N day entry to map atmosphere, including characterizing wind and turbulence

INSTRUMENTATION:
- Thermocouples: one at 17° off stagnation point (0.41 cm below heat-shield surface); another on conical frustrum ahead of shoulder (0.30 cm below heat-shield surface) at s/Rₐ=2.2

NOTES:
- Heating rates and loads are probably for non-ablating conditions.

REFERENCES:
MISSION: GENESIS
PLANET: EARTH RETURN
LAUNCH: AUG 8, 2001
ENTRY: SEP 8, 2004
MISSION DESCRIPTION:
To collect solar wind particles and return to Earth

INSTRUMENTATION:
- Thermosensitive paint strips

NOTES:
- The capsule crashed violently into the desert after failing to deploy the drag devices.
- Despite this mishap, many of the collectors remained intact and most of the mission goals should be accomplished.

REFERENCES:

Data Collected by: W. Willcockson and R. Bennett

MISSION: PIONEER-VENUS
SMALL “NIGHT PROBE”
PLANET: VENUS
LAUNCH: AUG 8, 1978
ENTRY: DEC 9, 1978
MISSION DESCRIPTION:
To map the atmosphere, including temperature and pressure, from a night side entry

INSTRUMENTATION:
- Thermocouples: one at 17° off stagnation point (0.41 cm below heat-shield surface); another on conical frustum ahead of shoulder (0.30 cm below heat-shield surface) at s/Rn=2.2

NOTES:
- Heating rates and loads are probably for non-ablating conditions.

REFERENCES:

Data Collected by: M. Tauber and G. Allen
**MISSION: PIONEER-VENUS  
**SMALL "DAY PROBE"  
**PLANET: VENUS  
**LAUNCH: Aug 8, 1978  
**ENTRY: Dec 9, 1978

**MISSION DESCRIPTION:**
To map the atmosphere, including radiative energy, from a day side entry

---

**INSTRUMENTATION:**
- Thermocouples: one at 17° off stagnation point (0.41 cm below heat-shield surface); another on conical frustum ahead of shoulder (0.30 cm below heat-shield surface) at s/Rₙ=2.2

**NOTES:**
- Heating rates and loads are probably for non-ablating conditions.

---

**REFERENCES:**

---

---

**MISSION: STARDUST  
**PLANET: EARTH RETURN  
**LAUNCH: Feb 7, 1999  
**ENTRY: Jan 15, 2006

**MISSION DESCRIPTION:**
To collect comet material from Wild 2 and return to Earth

---

**INSTRUMENTATION:**

**NOTES:**
- The Stardust capsule made a successful return to Earth on Jan 15, 2006.

---

**REFERENCES:**

---

---

**TRAJECTORY**
- **Entry angle**
  - -25.4° at 200 km
- **Shape**
  - Blunt-nosed, 45° half-cone angle
- **Trim L/D**
  - (specify trim α)
- **Material designation**
  - Carbon-phenolic
- **Inertial entry velocity**
  - 11.54 km/s
- **Nose radius**
  - 0.19 m
- **Ballistic coeff.**
  - 190 kg/m²
- **Thickness**
  - 1.2 cm at stagnation point
- **Stagnation heating rate**
  - 3900 W/cm²
- **Ablating? Ejected?**
  - Yes

**INSTRUMENTATION:**
- **TPS mass fraction, inc. insul.**
  - 12.9%
- **Radiative heat flux**
  - 1300 W/cm²
- **Resin dens. Matrix density**
  - 89.8% Carbon, 2.8% Hydrogen, 6.9% Oxygen
- **Velocity at peak heat**
  - 10.40 km/s
- **Vehicle mass**
  - 91 kg
- **Integrated heat load**
  - At stagn. pt., 14,000 J/cm³
- **Resin mat. Matrix mat.**
  - 100 kg/m³
- **Total material density**
  - 1490 kg/m³

---

**TRAJECTORY**
- **Entry angle**
  - -8.2° ± 0.08° @ 125 km
- **Shape**
  - Blunt-nosed 60° half-angle cone
- **Trim L/D**
  - (specify trim α)
- **Material designation**
  - PICA-15
- **Inertial entry velocity**
  - 12.8 km/s @ 125 km
- **Nose radius**
  - 0.23 m initial
- **Ballistic coeff. (Ablated)**
  - 60.0 kg/m²
- **Thickness**
  - 5.82 cm
- **Stagnation heating rate**
  - 1200 W/cm²
- **Ablating? Ejected?**
  - Yes

**INSTRUMENTATION:**
- **TPS mass fraction, inc. insul.**
  - 22%
- **Radiative heat flux**
  - 130 W/cm²
- **Resin dens. Matrix density**
  - 109 kg/m³
- **Vehicle mass**
  - 45.8 kg
- **Integrated heat load**
  - 36,000 J/cm³
- **Resin mat. Matrix mat.**
  - 160 kg/m³
- **PH stag. pressure**
  - 0.275 atm
- **Total material density**
  - 250 kg/m³ approx.
MISSION: DEEP SPACE 2
PLANET: MARS
LAUNCH: JAN 3, 1999
ENTRY: DEC 3, 1999
MISSION DESCRIPTION:
To penetrate the Martian surface with two small probes

---

MISSION: PIONEER-VENUS LARGE PROBE "SOUNDER"
PLANET: VENUS
LAUNCH: AUG 8, 1978
ENTRY: DEC 9, 1978
MISSION DESCRIPTION:
This probe contained 7 experiments, including one to measure the atmospheric composition

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<table>
<thead>
<tr>
<th>Trajectory</th>
<th>Geometry</th>
<th>Aero/thermal</th>
<th>TPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry angle</td>
<td>inertial -13.25° at 128 km</td>
<td>Shape 45° sphere-cone, spherical all</td>
<td>Trim L/D (specify trim α) 0</td>
</tr>
</tbody>
</table>

Inertial entry velocity
Nose radius 0.875 m
Ballistic coeff 36.2 kg/m²
Thickend ~1 cm

Relative entry velocity 6.9 km/s
Base area 0.96 m²
Stagnation heating rate 194 W/cm²
Not ejected

Velocity at peak heat 5.94 km/s
Vehicle mass 3.67 kg
Integrated heat load 8712 J/cm²
Resin mat. Matrix mat.

Control method Ballistic
TPS mass fraction, inc. insul.
Radiative heat flux
Resin dens. Matrix density

Center of Gravity, Xc/D .24
Payload mass
PH stag. pressure
Total material density

---

Instrumentation:

NOTES:
• The DS-2 aeroshells were on the failed Mars Polar Lander.
• They were to be jettisoned 5 minutes before the lander entered the Martian atmosphere. No signals from the probes were received.

---

REFERENCES:

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<table>
<thead>
<tr>
<th>Trajectory</th>
<th>Geometry</th>
<th>Aero/thermal</th>
<th>TPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry angle</td>
<td>-32.4° at 200 km</td>
<td>Shape Blunt-nosed, 45° half-cone angle</td>
<td>Trim L/D (specify trim α) 0</td>
</tr>
</tbody>
</table>

Inertial entry velocity 11.54 km/s
Nose radius 0.36 m
Ballistic coeff 188 kg/m²
Stagnation heating rate 4500 W/cm²
Ablating? Yes

Relative entry velocity Same
Base area 1.59 m²
Stagnation heating rate
Ablating? Ejected? Yes

Velocity at peak heat 10.50 km/s
Vehicle mass 316.48 kg
Integrated heat load 12,400 J/cm²
Resin mat. Matrix mat.
89.8% Carbon 2.8% Hydrogen 6.9% Oxygen

Control method Ballistic
TPS mass fraction, inc. insul.
Radiative heat flux 2400 W/cm²
Resin dens. Matrix density

Center of Gravity, Xc/D 0.40
Payload mass
Science instr. 29.15 kg (9.2%)
PH stag. pressure 5.30 atm Total material density 1490 kg/m³

---

Instrumentation:

NOTES:
• Thermocouples: one at the stagnation point (0.41 cm below heat-shield surface); another on conical frustum ahead of shoulder (0.30 cm below heat-shield surface) at s/Rn=2.2

---

REFERENCES:

---

Data Collected by: M. Tauber and M. Trauber 22
Data Collected by: M. Tauber and G. Allen 15
MISSION: GALILEO
PLANET: JUPITER
LAUNCH: Oct 18, 1989
ENTRY: Dec 7, 1995

Mission Description:
To descend into the Jovian atmosphere, collect atmospheric data and relay to the orbiter

<table>
<thead>
<tr>
<th>Trajectory</th>
<th>Geometry</th>
<th>Aero/thermal</th>
<th>TPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry angle</td>
<td>Inertial: -6.64°, Rel: -8.5°, @ 450 km</td>
<td>Blunt-nosed, 44.86° half cone angle</td>
<td>Trim L/D (specify trim a)</td>
</tr>
<tr>
<td>Shape</td>
<td>Thickness</td>
<td>14.6 cm at stagnation</td>
<td></td>
</tr>
<tr>
<td>Inertial entry velocity</td>
<td>59.92 km/s</td>
<td>Ballistic coeff. (at entry)</td>
<td>256 kg/m²</td>
</tr>
<tr>
<td>Nose radius (initial)</td>
<td>.222 m</td>
<td>Stagnation heating rate</td>
<td>17,000 W/cm²</td>
</tr>
<tr>
<td>Relative entry velocity</td>
<td>47.37 km/s</td>
<td>Ablating? Ejected?</td>
<td>Yes</td>
</tr>
<tr>
<td>Base area (at entry)</td>
<td>1.26 m²</td>
<td>Max recorded temp. was 950-1050°C</td>
<td></td>
</tr>
<tr>
<td>Velocity at peak heat (relative)</td>
<td>39.0 km/s</td>
<td>Ablating? Ejected?</td>
<td>Yes, but low</td>
</tr>
<tr>
<td>Vehicle mass</td>
<td>335 kg</td>
<td>Integrated heat load</td>
<td>200,000 J/cm² with ablation</td>
</tr>
<tr>
<td>At entry</td>
<td></td>
<td>Resin mat.</td>
<td>Matrix mat.</td>
</tr>
<tr>
<td>Control method</td>
<td>Ballistic</td>
<td>Phenolic Carbon</td>
<td></td>
</tr>
<tr>
<td>Center of Gravity, X/D</td>
<td>.3447 see note</td>
<td>Payload mass</td>
<td>Science 8.3%</td>
</tr>
<tr>
<td>Forebody TPS</td>
<td>TPS mass fraction, inc. insul.</td>
<td>Peak Heat stagn. pressure</td>
<td>7.3 atm</td>
</tr>
<tr>
<td>Radiative heat flux (sting point)</td>
<td>17,000 W/cm² (with ablation)</td>
<td>Total material density</td>
<td>1450 kg/m²</td>
</tr>
</tbody>
</table>

Instruments:
- Forebody TPS: ablation recession gauges
- Afterbody TPS: thermocouples in the nylon phenolic

Notes:
- Reported CG estimates varied widely.

References:

MISSION: ARD
"Atmospheric Reentry Demonstrator"
PLANET: EARTH
LAUNCH: Oct 21, 1998
ENTRY: Oct 21, 1998

Mission Description:
To undertake a complete space flight cycle for ESA, with emphasis on reentry technologies

<table>
<thead>
<tr>
<th>Trajectory</th>
<th>Geometry</th>
<th>Aero/thermal</th>
<th>TPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry angle</td>
<td>-2.6°</td>
<td>Shape</td>
<td>Apollo-like capsule, 33° cone</td>
</tr>
<tr>
<td>Inertial entry velocity</td>
<td>8.01 km/s</td>
<td>Nose radius</td>
<td>3.36 m</td>
</tr>
<tr>
<td>Nose radius</td>
<td>Ballistic coeff.</td>
<td>403 kg m²</td>
<td></td>
</tr>
<tr>
<td>Stagnation heating rate</td>
<td>7.54 km/s</td>
<td>Base area</td>
<td>6.15 m²</td>
</tr>
<tr>
<td>Velocity at peak heat</td>
<td>2715 kg (inc. 1017 kg front heat shield)</td>
<td>Integrated heat load</td>
<td>Designed for 17,700 J/cm²</td>
</tr>
<tr>
<td>Vehicle mass</td>
<td>Resin mat.</td>
<td>Matrix mat.</td>
<td></td>
</tr>
<tr>
<td>Control method</td>
<td>RCS: 7 thrusters</td>
<td>TPS mass fraction, inc. insul.</td>
<td>23% (626 kg TPS)</td>
</tr>
<tr>
<td>Radiative heat flux</td>
<td>Max design 110 W/cm²</td>
<td>Resin dens.</td>
<td>Matrix density</td>
</tr>
<tr>
<td>Center of Gravity, X/D</td>
<td>.256</td>
<td>Payload mass</td>
<td>No payload</td>
</tr>
<tr>
<td>Payload mass</td>
<td>PH stagn. pressure</td>
<td>.22 atm</td>
<td></td>
</tr>
<tr>
<td>Total material density</td>
<td>Norcoat: 0.47 Aleastrail: 1.65</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Instrumentation:
- The capsule afterbody was instrumented with 7 surface pressure sensors, 2 thermal plugs with 2 thermocouples each on the back cover, and 4 surface-mounted copper calorimeters on the cylindrical section.
- The front cone contained 18 pressure sensors, 14 thermal plugs with 3 or 5 TC each.

Notes:
- Aleastril: silica fibers with phenolic resin; Norcoat: cork powder and phenolic resin.
- 4 experimental Ceramic Matrix Composite (CMC) tiles and samples of Flexible External Insulation (FEI)

References:

Data Collected by: F. Casaux and M.J. Wright
MISSION: HUYGENS
PLANET: TITAN
A moon of Saturn
LAUNCH: Oct 15, 1997
ENTRY: Jan 14, 2005
MISSION DESCRIPTION:
To explore the atmosphere of Titan

<table>
<thead>
<tr>
<th>Trajectory</th>
<th>Geometry</th>
<th>Aero/thermal</th>
<th>TPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry angle</td>
<td>Relative ~3.17°</td>
<td>Shape</td>
<td>Nose radius</td>
</tr>
<tr>
<td>Inertial entry velocity</td>
<td>7.8 km/s</td>
<td>Nose radius</td>
<td>1.35 m</td>
</tr>
<tr>
<td>Relative entry velocity</td>
<td>7.43 km/s</td>
<td>Base area</td>
<td>9.08 m²</td>
</tr>
<tr>
<td>Velocity at peak heat</td>
<td>6.4 km/s</td>
<td>Vehicle mass</td>
<td>761 kg at entry</td>
</tr>
<tr>
<td>Control method</td>
<td>RCS</td>
<td>TPS mass fraction, inc. insul.</td>
<td>Radiative heat flux</td>
</tr>
<tr>
<td>Center of Gravity, Xc/G</td>
<td>.254</td>
<td>Payload mass</td>
<td>PH stag. Pressure</td>
</tr>
</tbody>
</table>

INSTRUMENTATION:
- No aerohading data
- A mass spectrometer for atmospheric composition was deployed after the heat shield was ejected.

NOTES:
- Huygens is a European Space Agency probe that was carried by the Cassini Saturn Orbiter.
- AQ60 silica fibers reinforced by phenolic resin

REFERENCES:

MISSION: OREX
PLANET: EARTH
LAUNCH: Feb 4, 1994
ENTRY: Feb 4, 1994
MISSION DESCRIPTION:
To collect information on the design of a re-entry vehicle to support Japanese unmanned space shuttle HOPE

<table>
<thead>
<tr>
<th>Trajectory</th>
<th>Geometry</th>
<th>Aero/thermal</th>
<th>TPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry angle</td>
<td>Relative -65.4°</td>
<td>Shape</td>
<td>60° sphere-cone</td>
</tr>
<tr>
<td>Inertial entry velocity</td>
<td>6.0 km/s at 1270 km</td>
<td>Nose radius</td>
<td>1.25 m</td>
</tr>
<tr>
<td>Relative entry velocity</td>
<td>6.0 km/s</td>
<td>Base area</td>
<td>5.73 m²</td>
</tr>
<tr>
<td>Velocity at peak heat</td>
<td>~5.1 km/s</td>
<td>Vehicle mass</td>
<td>318 kg</td>
</tr>
<tr>
<td>Control method</td>
<td>Ballistic</td>
<td>TPS mass fraction, inc. insul.</td>
<td>Radiative heat flux</td>
</tr>
<tr>
<td>Center of Gravity, Xc/G</td>
<td>1.51 m</td>
<td>Payload mass</td>
<td>PH stag. Pressure</td>
</tr>
</tbody>
</table>

INSTRUMENTATION:
- Wall catalycity measurement, electrostatic probe, and heat shield temperature sensors

NOTES:
- RCS was used to maintain a trim angle of attack of zero

REFERENCES:
MISSION: PATHFINDER
"SOJOURNER"
PLANET: MARS

LAUNCH: Dec 4, 1996
ENTRY: Jul 4, 1997

MISSION DESCRIPTION:
To demonstrate a simple, low-cost system for placing a science payload on the surface of Mars

Instrumentation:
- TPS instrumented with thermocouples only

Notes:
- Spin stabilized

<table>
<thead>
<tr>
<th>Trajectory</th>
<th>Geometry</th>
<th>Aero/thermal</th>
<th>TPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry angle</td>
<td>Inertial -14.06°</td>
<td>Shape</td>
<td>70° sphere-cone</td>
</tr>
<tr>
<td>Inertial entry velocity</td>
<td>7.26 km/s</td>
<td>Nose radius</td>
<td>0.66 m</td>
</tr>
<tr>
<td>Relative entry velocity</td>
<td>7.48 km/s</td>
<td>Base area</td>
<td>5.52 m²</td>
</tr>
<tr>
<td>Velocity at peak heat</td>
<td>Relative: 6.61 km/s</td>
<td>Vehicle mass</td>
<td>585.3 kg</td>
</tr>
<tr>
<td>Control method</td>
<td>Ballistic</td>
<td>TPS mass fraction, inc. insul.</td>
<td>6.2% fore body, 2% back shell</td>
</tr>
<tr>
<td>Center of Gravity, Xc/D</td>
<td>.27</td>
<td>Payload mass</td>
<td>PH stag. pressure</td>
</tr>
</tbody>
</table>

Mission data:
- 3 acceleration sensors, 3 angular rate sensors, 24 thermocouples, RAFLEx (pressure, temperature & heat flux sensors) and PYREX (pyrometric temperature measurements)

Notes:
- CFRP: Carbon Fiber Reinforced Plastics
- SPA: Surface Protected Ablator
- This was the first successful Western European re-entry mission.

References:

MISSION: MIRKA
PLANET: EARTH

LAUNCH: Oct 9, 1997
ENTRY: Oct 23, 1997

MISSION DESCRIPTION:
To qualify a re-entry heat-shield concept with scientific and engineering experiments conducted by German researchers

Instrumentation:
- 3 acceleration sensors, 3 angular rate sensors, 24 thermocouples, RAFLEx (pressure, temperature & heat flux sensors) and PYREX (pyrometric temperature measurements)

Notes:
- CFRP: Carbon Fiber Reinforced Plastics
- SPA: Surface Protected Ablator
- This was the first successful Western European re-entry mission.

References: