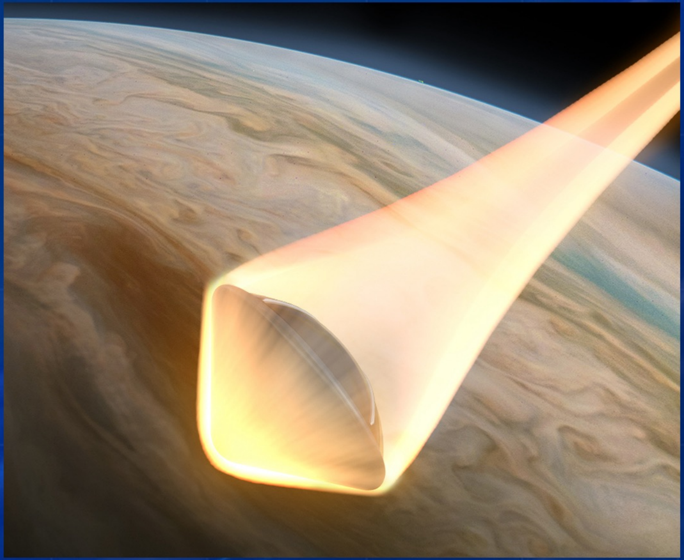
National Aeronautics and Space Administration

Planetary Mission Entry Vehicles

QUICK REFERENCE GUIDE | VERSION 4.1



NASA AMES RESEARCH CENTER

ENTRY SYSTEMS AND TECHNOLOGY DIVISION

NASA/SP-20230010341

PLANETARY MISSION ENTRY VEHICLES

Quick Reference Guide Version 4.1

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Version 4.1: This version adds the Phoenix, InSIGHT, LOFTID and Artemis I missions and updates data entries to the missions from previous versions with corrected and/or added data.

To all those who have contributed to either previous versions of the “Blue Book” or have volunteered to send in information to our current release, thank you. Without the support of our community, this book would not be possible.

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Planetary Mission Entry Vehicles

QUICK REFERENCE GUIDE

VERSION **4.1**

NASA AMES RESEARCH CENTER

ENTRY SYSTEMS AND TECHNOLOGY DIVISION

Back in the era before ubiquitous portable electronics with instantaneous access to all the world's information at a fingertip, one had to rely on dead-reckoning to compare new concepts with historical analogs. This effect permeated all our endeavors and certainly so in the niche world of planetary entry vehicles. So, it was in the days of designing the Stardust return capsule that in meetings, more often than not, someone would ask, "how does this <heat rate, cone angle, g-load...> compare to <Apollo, Viking, Galileo...>?" Thus was born V1 of the Planetary Mission Entry Vehicles Quick Reference Guide, thereafter, dubbed the "Probe Blue Book," containing the high-level characteristics of past entry systems and easily tucked into a daily planner, notebook, or other carry-along work aid.

Now that cell phones with global internet access are here, seemingly the era of the Probe Blue Book has passed. Yet ironically, we now suffer too much information. To obtain that one useful, comparative number becomes an exercise of selecting judicious search terms then reconciling conflicting results. Persisting in its convenient form and function, this 4th version contains an expanded set of missions as well as additional information on each mission. Inevitably, there are ambiguities and uncertainties in the data contained herein. There are often differences between design vs. construction, nominal vs. upper limit, and directly measured vs. inferred. In general, preference is given to best estimates of as-built construction and as-flown conditions. In some cases, references are cited. In other cases, the editors made best estimates. In all cases, an attempt is made to state the provenance of the listed value. References are included as an entry point into the publication record.

The editors would be appreciative of suggested corrections or clarifications to improve future versions of the guide. While it must be acknowledged that an Entry Vehicle is merely a tool (usually disposable!) toward achieving a greater goal of scientific discovery or expanding human presence, still there is excitement in the vehicle itself; our own shooting star containing and preserving the wishes of our collective human enterprise of discovery.

Dean Kontinos
Chief Engineer
NASA Ames Research Center

Explanation of data types:

Best-estimated: Derived from information on the as-built and as-flown spacecraft configuration and mission. These values are based on any available flight telemetry along with Best-Estimated Trajectory (BET) and follow-on simulation data.

Design: Derived from information from spacecraft project design documents. These may deviate from what a best-estimated value would be due to design unknowns and conservatisms.

Editor’s Estimate: Derived from editor research and simulations, where design information is unavailable or in conflict. This is a credible engineering estimate.

Explanation of symbols used for each data type:

Geometry	**Aerothermal**	**TPS**	**Parachutes**
Use 123 for Best-estimated	Use 123 for Best-estimated	Use 123 for Best-estimated	Use 123 for Best-estimated
[123] for design	[123] for design	[123] for design	[123] for design
~123 for editor's estimate	~123 for editor's estimate	~123 for editor's estimate	~123 for editor's estimate
		Use (1), (2), (3) to designate multiple materials	Use (1), (2), (3) to indicate multiple parachute stages, as per Table 3 of AIAA 2006-6792

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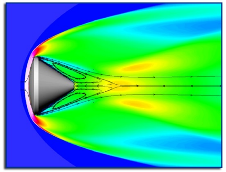
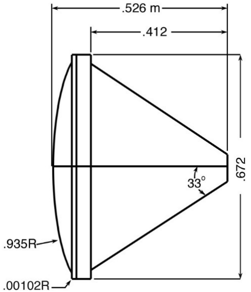
MISSION: FIRE II
PLANET: EARTH
LAUNCH: MAY 22, 1965
ENTRY: MAY 22, 1965



MISSION DESCRIPTION: Pile driver flight test of a scaled Apollo CM geometry to measure reentry heating environment. Launched with Atlas D LV then pile driven into atmosphere to high speed with Antares II-A5 rocket motor.

INSTRUMENTATION: 3 forebody calorimeters, 11 forebody thermocouples,12 offset radiometer thermocouples and one static pressure transducer on the afterbody.

NOTES: This aerothermal flight test was to evaluate radiative heating for Apollo. The reentry package consisted of three nested phenolic-asbestos heatshields sandwiched between three beryllium calorimeters that ablated or melted away, therefore the mass and OML changed with time.



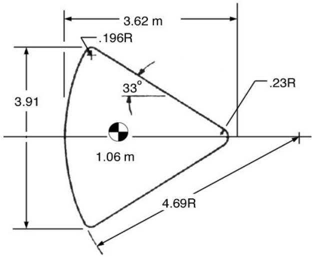
Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Inertial: -14.24°	**Shape**	spherical section	**Velocity at peak heat**	10.2 km/s	**Forebody material designation**	See note above	**Type**	N/A
Entry velocity: inertial & relative	Inertial: 11.74 km/s Relative: 11.35 km/s	**Nose radius**	0.935 m 0.805 m 0.702 m	**Peak convective heating**	~920 W/cm²	**Forebody thickness & mass**	0.3 cm	**Deployment method**	N/A
Trim L/D (specify trim α)	0° (spin stabilized)	**Base area**	0.354 m² 0.312 m² 0.271 m²	**Peak radiative heating**	~350 W/cm² (.2-.4μ) implying ~650 total Traj value 487 W/cm²	**Ablating Ejected**	Fore: ablated and melted Aft: ablated	**Reference diameter / area**	N/A
Control method	Ballistic, spin stabilized	**Vehicle mass**	86.57 kg	**Integrated total heatload**	16136 W/cm²	**TPS Integration method**	Nested/ layered TPS	**Deployment Mach**	N/A
Ballistic co-eff.	164.1 kg/m²	**Payload mass**	N/A	**PH stag. pressure**	1.046 atm	**Aftbody material designation**	Phenolic-asbestos and silicon elastomer	**Deployment dynamic pressure**	N/A
Peak deceleration	~77.2 g	**TPS mass fraction, inc. insul.**		**Peak stag. heating rate**	1339 W/cm²	**Aftbody thickness & mass**		**Parachute materials**	N/A

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; 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.



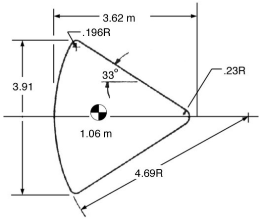
Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Inertial: -8.58° Relative: -9.03°	**Shape**	Capsule: 33° cone	**Velocity at peak heat**	5.73 km/s	**Forebody material designation**	Avco 5026-39 HC	**Type**	(1) 2 conical ribbon drogue parachutes, (2) 3 ringshot pilot parachutes, (3) 3 ringsail main parachutes
Entry velocity: inertial & relative	Relative: 7.67 km/s	**Nose radius**	4.69 m, 3 m effective	**Peak convective heating**	186 W/cm² at peak	**Forebody thickness & mass**	Ablator = 4.32 cm, braised stainless-steel substructure (PH 15-7 MO)=5.08 cm	**Deployment method**	(1) mortar (2) drogue parachute (3) pilot parachute
Trim L/D (specify trim α)	-19.7° < α < 21.3°	**Base area**	12.02 m²	**Peak radiative heating**	0 W/cm²	**Ablating Ejected**	Ablated: yes Ejected: no	**Reference diameter / area**	(1) 4.9 m dia. (2) 2.2 m dia. (3) 25.5 m dia.
Control method	No control: rolled	**Vehicle mass**	5027.48 kg	**Integrated total heatload**	7600 J/cm²	**TPS integration method**	Honeycomb bonded to substructure; cells filled w/ablative compound	**Deployment Mach**	~0.7
Ballistic co-eff.		**Payload mass**	N/A	**PH stag. pressure**	0.85 atm	**Aftbody material designation**		**Deployment dynamic pressure**	
Peak deceleration	14.3 g	**TPS mass fraction, inc. insul.**	13.7%	**Peak stag. heating rate**	186 W/cm² at peak	**Aftbody thickness & mass**		**Parachute materials**	

MISSION: APOLLO AS-202 (APOLLO-3)
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.

INSTRUMENTATION: 36 pressure sensors all worked; 35 calorimeters worked initially.

NOTES: TPS thickness: Ablator = 4.32 cm, braised stainless-steel substructure (PH 15-7 MO) = 5.08 cm. Insulation: (TG-15000) = 2.03 cm, aluminum honeycomb (2014-T6 and 5052-H39) = 3.81 cm Manufacture: AVCO Corp.



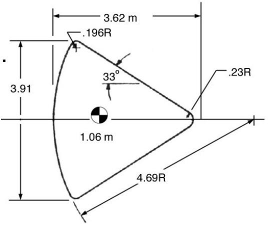
Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Inertial -3.57° Relative -3.74° Entry altitude 121.67 km	**Shape**	Capsule 33°cone	**Velocity at peak heat**	7.94 km/s	**Forebody material designation**	Avco 5026-39 HC	**Type**	(1) 2 conical ribbon drogue parachutes, (2) 3 ringshot pilot parachutes, (3) 3 ringsail main parachutes
Entry velocity: inertial & relative	Inertial: 8.75° km/s Relative: 8.35 km/s	**Nose radius**	4.59 m, 3 m effective	**Peak convective heating**	59.2 W/cm² at peak	**Forebody thickness & mass**	Ablator = 4.32 cm braised stainless-steel substructure (PH 15-7 MO) = 5.08 cm	**Deployment method**	(1) mortar (2) drogue parachute (3) pilot parachute
Trim L/D (specify trim α)	0.372 Avg. Resultant L/D	**Base area**	12.2 m²	**Peak radiative heating**	0 W/cm²	**Ablating Ejected**	Ablated: yes Ejected: no	**Reference diameter / area**	(1) 4.9 m dia. (2) 2.2 m dia. (3) 25.5 m dia.
Control method	Roll modulation	**Vehicle mass**	5424.51 kg	**Integrated total heatload**	18789 J/cm²	**TPS integration method**	Honeycomb bonded to substructure; cells filled with ablative compound	**Deployment Mach**	~0.7
Ballistic co-eff.	N/A	**Payload mass**	Apollo CM test flight	**PH stag. pressure**	0.11 atm	**Aftbody material designation**		**Deployment dynamic pressure**	
Peak deceleration		**TPS mass fraction, inc. insul.**	13.7%	**Peak stag. heating rate**	59.2 W/cm² at peak	**Aftbody thickness & mass**		**Parachute materials**	

MISSION: APOLLO AS-501 (APOLLO-4)
PLANET: EARTH
LAUNCH: NOV 9, 1967
ENTRY: NOV 9, 1967

MISSION DESCRIPTION*:* Test of Saturn V launch vehicle and overall reentry operations.

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.



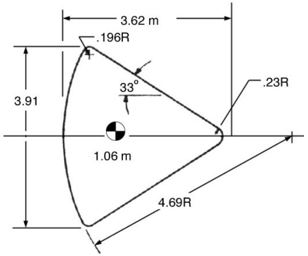
Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Inertial -6.93 Relative-7.19° Entry altitude 121.92 km	**Shape**	Capsule: 33° cone	**Velocity at peak heat**	10.04 km/s	**Forebody material designation**	Avco 5026-39 HC	**Type**	(1) 2 conical ribbon drogue parachutes, (2) 3 ringshot pilot parachutes, (3) 3 ringsail main parachutes
Entry velocity: inertial & relative	Inertial: 11.14 km/s Relative: 10.73 km/s	**Nose radius**	4.66 m, 3 m effective	**Peak convective heating**	219 W/cm²	**Forebody thickness & mass**	TPS thickness: Ablator = 4.32 cm, braised stainless-steel substructure (PH 15-7 MO) = 5.08 cm	**Deployment method**	(1) mortar (2) drogue parachute (3) pilot parachute
Trim L/D (specify trim α)	0.37 < L/D < 0.44 24° < α <28°	**Base area**	12.08 m²	**Peak radiative heating**	317 W/cm²	**Ablating Ejected**	Ablated: yes Ejected: no	**Reference diameter / area**	(1) 4.9 m dia. (2) 2.2 m dia. (3) 25.5 m dia.
Control method	Roll modulation	**Vehicle mass**	5424.5 kg	**Integrated total heatload**	24122 J/cm²	**TPS integration method**	Honeycomb bonded to substructure; cells filled with ablative compound	**Deployment Mach**	~0.7
Ballistic co-eff.	~340 kg/m²	**Payload mass**	N/A	**PH stag. pressure**	0.542 atm	**Aftbody material designation**		**Deployment dynamic pressure**	
Peak deceleration	8.79 g	**TPS mass fraction, inc.insul.**	13.7%	**Peak stag. heating rate**	527 W/cm² peak	**Aftbody thickness & mass**		**Parachute materials**	

MISSION: APOLLO AS-502 (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.

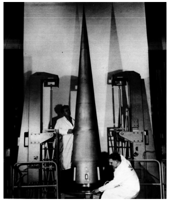
INSTRUMENTATION:

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.
Manufacture: AVCO Corp Saturn-V malfunctioned causing the CM to follow a spurious return trajectory.



Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Inertial: -5.9°	**Shape**	Capsule: 33° cone	**Velocity at peak heat**	8.32 km/s	**Forebody material designation**	Avco 5026-39 HC	**Type**	(1) 2 conical ribbon drogue parachutes, (2) 3 ringshot pilot parachutes, (3) 3 ringsail main parachutes
Entry velocity: inertial & relative	Inertial: 10.00 km/s Relative: 9.60 km/s	**Nose radius**	4.69 m, 3 m effective	**Peak convective heating**	197 W/cm²	**Forebody thickness & mass**	TPS thickness: Ablator = 4.32 cm, braised stainless-steel substructure (PH 15-7 MO) = 5.08 cm	**Deployment method**	(1) mortar (2) drogue parachute (3) pilot parachute
Trim L/D (specify trim α)	0.35 < L/D <0.4 24°< α <28°	**Base area**	12.02 m²	**Peak radiative heating**	43 W/cm²	**Ablating Ejected**	Ablated: yes Ejected: no	**Reference diameter / area**	(1) 4.9 m dia. (2) 2.2 m dia. (3) 25.5 m dia.
Control method	Roll modulation	**Vehicle mass**	5424.9 kg	**Integrated total heatload**	32000 J/cm²	**TPS integration method**	Honeycomb bonded to substructure; cells filled with ablative compound	**Deployment Mach**	~0.7
Ballistic co-eff.	395.8 kg/m²	**Payload mass**	N/A	**PH stag. pressure**	0.354 atm	**Aftbody material designation**		**Deployment dynamic pressure**	
Peak de-celeration		**TPS mass fraction, inc insul**	13.7%	**Peak stag. heating rate**	240 W/cm² peak	**Aftbody thickness & mass**		**Parachute materials**	

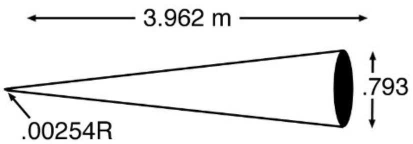
MISSION: REENTRY F
PLANET: EARTH
LAUNCH: APR 27, 1968
ENTRY: APR 27, 1968



MISSION DESCRIPTION*:* To measure turbulent heating rates and transition onset in a flight environment.

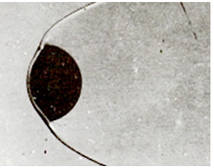
INSTRUMENTATION: Multiple thermocouples and pressure sensors at 21 stations on cone, 4 heat-flux gauges and 2 pressure gauges on base. 3 thermocouples in nose-tip assembly.

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 3. The beryllium heat shield melted for ~40 seconds after entry.



Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	-20.78°	**Shape**	5° half cone, 3.962 m long	**Velocity at peak heat**	5.47 km/s	**Forebody material designation**	Nose-tip: ATJ graphite Body: beryllium	**Type**	N/A
Entry velocity: inertial & relative	Inertial: 6.28 km/s Relative: 5.96 km/s	**Nose radius**	0.254 cm	**Peak convective heating**	32 W/cm²	**Forebody thickness & mass**	Be: 1.524 cm	**Deployment method**	N/A
Trim L/D (specify trim α)	0° ballistic	**Base area**	0.3772 m²	**Peak radiative heating**	~0 W/cm²	**Ablating Ejected**	Nose-tip: yes Ejected: no	**Reference diameter / area**	N/A
Control method	N/A	**Vehicle mass**	272 kg	**Integrated total heatload**		**TPS integration method**		**Deployment Mach**	N/A
Ballistic co-eff.	~50000 kg/m²	**Payload mass**	N/A	**PH stag. pressure**	250 atm	**Aftbody material designation**		**Deployment dynamic pressure**	N/A
Peak deceleration		**TPS mass fraction, inc. insul.**		**Peak stag. heating rate**	32 W/cm²	**Aftbody thickness & mass**		**Parachute materials**	N/A

MISSION: PAET
PLANET: EARTH
LAUNCH: JUL 2, 1971
ENTRY: JUL 2, 1971

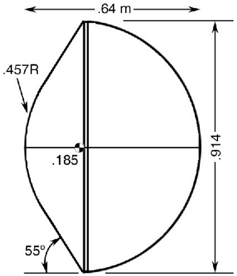


Shadowgraph of PAET Model in Ballistic Range Test

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

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:



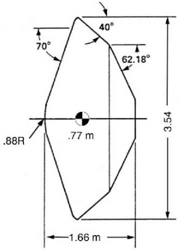
Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Relative: -41° Inertial: -38.98° 93 km altitude	**Shape**	Blunt-nose, 55° half-cone angle	**Velocity at peak heat**	5.7 km/s	**Forebody material designation**	Nose: Beryllium heatsink Conical frustum: ESA 3560 ablator	**Type**	N/A
Entry velocity: inertial & relative	Inertial: 6.88 km/s Relative: 6.66 km/s	**Nose radius**	0.457 m	**Peak convective heating**	~228 W/cm²	**Forebody thickness & mass**	Nose: 1-2.5 cm Conical frustum: 0.76 cm	**Deployment method**	N/A
Trim L/D (specify trim α)	0	**Base area**	0.66 m²	**Peak radiative heating**	Negligible	**Ablating Ejected**	Frustum ablated Ejected: no	**Reference diameter / area**	N/A
Control method	Ballistic	**Vehicle mass**	62.1 kg	**Integrated total heatload**	Stag. pt. 1982 J/cm²	**TPS integration method**	None (solid Be)	**Deployment Mach**	N/A
Ballistic co-eff.	68.4 kg/m²	**Payload mass**	14 kg	**PH stag. pressure**	0.60 atm	**Aftbody material designation**		**Deployment dynamic pressure**	N/A
Peak deceleration	76 g	**TPS mass fraction, inc. insul.**	Forebody: 13.7% Afterbody: 3.5%	**Peak stag. heating rate**	Max: 228 W/cm² (no ablation)	**Aftbody thickness & mass**		**Parachute materials**	N/A

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.

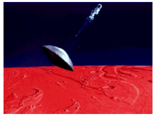
INSTRUMENTATION: The forebody aeroshell was not instrumented, but the wake enclosure (backshell) had thermocouples. There was one pressure port off stagnation point and one on the base cover. Temperature gauges were on the back face and on both backshell frustums.

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



Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Inertial: -17.00° Relative: -17.76° Entry altitude 242.8 km	**Shape**	70° sphere -cone	**Velocity at peak heat**	4.06 km/s	**Forebody material designation**	SLA561-V	**Type**	Single DGB parachute
Entry velocity: inertial & relative	Inertial: 4.610 km/s Relative: 4.418 km/s	**Nose radius**	0.8763 m	**Peak convective heating**	21.1 W/cm²	**Forebody thickness & mass**	Variable: (max) 1.38 cm	**Deployment method**	Main parachute directly deployed by 15 in. diameter mortar
Trim L/D (specify trim α)	α = -11.1°	**Base area**	9.84 m²	**Peak radiative heating**	0	**Ablating Ejected**	Ablator-pyrolyzed Ejected: yes	**Reference diameter / area**	16.2 m dia.
Control method	3-axis RCS rate limiting	**Vehicle mass**	982.9 kg	**Integrated total heatload**	~1001 J/cm²	**TPS integration method**	Honeycomb bonded to substructure; cells filled with ablative compound	**Deployment Mach**	~1.1
Ballistic co-eff.	At peak dyn. p.: 60.41 kg/m²	**Payload mass**	N/A	**Peak heating stag. pressure**	0.06 atm	**Aftbody material designation**	Inner cone: laminated glass fabric/phenolic resin; outer cone: aluminum	**Deployment dynamic pressure**	~380 Pa
Peak deceleration	~6.86 g	**TPS mass fraction, inc. insul.**	2.8%	**Peak stag. heating rate**	Peak: 21.1 W/cm²	**Aftbody thickness & mass**		**Parachute materials**	Dacron

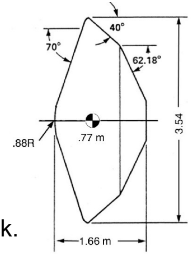
MISSION: VIKING LANDER 2
PLANET: MARS
LAUNCH: SEP 9, 1975
ENTRY: SEP 3, 1976



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

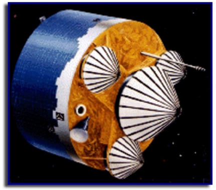
INSTRUMENTATION: The forebody aeroshell was not instrumented, but the wake enclosure (backshell) had thermocouples. There was one pressure port off stagnation point and one on the base cover. Temperature gauges were on the back face and on both backshell frustums.

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



Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Inertial: -17.08° Relative: -17.62° Entry altitude 240.99 km	**Shape**	Blunt-nosed 70° half cone	**Velocity at peak heat**	4.1 km/s	**Forebody material designation**	SLA561-V	**Type**	Single GBD parachute
Entry velocity: inertial & relative	Inertial: 4.61 km/s Relative: 4.48 km/s	**Nose radius**	0.876 m	**Peak convective heating**	~21.95 W/cm²	**Forebody thickness & mass**	Variable: (max) 1.38 cm	**Deployment method**	Main parachute directly deployed by 15 in. diameter mortar
Trim L/D (specify trim α)	0.18 at α = -11.3°	**Base area**	9.84 m²	**Peak radiative heating**	0	**Ablating Ejected**	Ablator-pyrolyzed Ejected: yes	**Reference diameter / area**	16.2 m dia.
Control method	3-axis RCS rate limiting	**Vehicle mass**	981.6 kg	**Integrated total heatload**	~1043 J/cm²	**TPS integration method**	Honeycomb bonded to substructure; cells filled with ablative compound	**Deployment Mach**	~1.1
Ballistic co-eff.	61.44 kg/m²	**Payload mass**	N/A	**PH stag. pressure**	~0.041 atm	**Aftbody material designation**	Inner cone: laminated glass fabric/phenolic resin; outer cone: aluminum	**Deployment dynamic pressure**	~408 pa
Peak deceleration	~7.2 g trajectory ~8.5 g chute snap	**TPS mass fraction, inc. insul.**	2.8%	**Peak stag. heating rate**	Max: 21.95 W/cm²	**Aftbody thickness & mass**		**Parachute materials**	Dacron

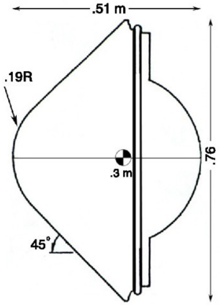
MISSION: PIONEER-VENUS: SMALL ‘NORTH PROBE’
PLANET: VENUS
LAUNCH: AUG 8, 1978
ENTRY: : DEC 9, 1978



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 frustum ahead of shoulder (0.30 cm below heat-shield surface) at s/Rn = 2.2.

NOTES: Heating rates and loads are based on Tauber correlations in radiative equilibrium (very model sensitive). Pioneer-Venus "North Probe" experienced 466 g which was greatest for a successful probe.



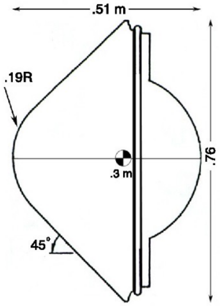
Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Inertial & Relative: -68.74° @ 200 km	**Shape**	Blunt-nosed, 45° half-cone angle	**Velocity at peak heat**	10.83 km/s	**Forebody material designation**	Carbon-phenolic FM 5055	**Type**	N/A
Entry velocity: inertial & relative	Inertial & Relative: 11.54 km/s	**Nose radius**	0.19 m	**Peak convective heating**	~3085 W/cm²	**Forebody thickness & mass**	1.2 cm at stagnation point	**Deployment method**	N/A
Trim L/D (specify trim α)	0	**Base area**	0.46 m²	**Peak radiative heating**	~3273 W/cm²	**Ablating Ejected**	Ablated: yes Ejected: no	**Reference diameter / area**	N/A
Control method	Ballistic	**Vehicle mass**	91 kg	**Integrated total heatload**	At stag. pt ~10502 J/cm²	**TPS integration method**	Nose: chopped molded; conical section: tape-wrapped	**Deployment Mach**	N/A
Ballistic co-eff.	190 kg/m²	**Payload mass**	3.60 kg	**Peak heating stag. pressure**	~16.5 atm	**Aftbody material designation**		**Deployment dynamic pressure**	N/A
Peak deceleration	465.9 g	**TPS mass fraction, inc. insul.**	12.9%	**Peak stag. heating rate**	6150 W/cm²	**Aftbody thickness & mass**		**Parachute materials**	N/A

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.



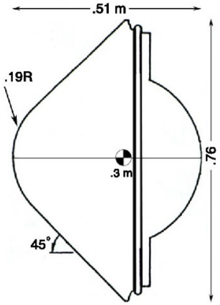
Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Inertial & Relative: -41.50° @ 200 km	**Shape**	Blunt-nosed, 45.2° half-cone angle	**Velocity at peak heat**	~10.79 km/s	**Forebody material designation**	Carbon-phenolic FM 5055	**Type**	N/A
Entry velocity: Inertial & Relative	Inertial & Relative: 11.54	**Nose radius**	0.19 m	**Peak convective heating**	~2743 W/cm²	**Forebody thickness & mass**	1.2 cm at stagnation point	**Deployment method**	N/A
Trim L/D (specify trim α)	0	**Base area**	0.46 m²	**Peak radiative heating**	~2330 W/cm²	**Ablating Ejected**	Ablated: yes Ejected: no	**Reference diameter / area**	N/A
Control method	Ballistic	**Vehicle mass**	91 kg	**Integrated total heatload**	At stag.pt ~11413 J/cm²	**TPS integration method**	Nose: chopped molded; conical section: tape-wrapped	**Deployment Mach**	N/A
Ballistic co-eff.	190 kg/m²	**Payload mass**	3.60 kg	**Peak heating stag. pressure**	~4.9 atm	**Aftbody material designation**		**Deployment dynamic pressure**	N/A
Peak deceleration	353.7 g	**TPS mass fraction, inc. insul.**	12.9%	**Peak stag. heating rate**	~4906 W/cm²	**Aftbody thickness & mass**		**Parachute materials**	N/A

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. Day Probe survived surface impact (accidentally) or 1 hour, 7.58 minutes.



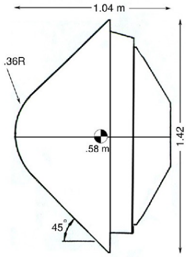
Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Inertial: -25.41° Relative: -25.42° @ 200 km	**Shape**	Blunt-nosed, 45° half-cone angle	**Velocity at peak heat**	10.68 km/s	**Forebody material designation**	Carbon-phenolic FM 5055	**Type**	N/A
Entry velocity: inertial & relative	Inertial & Relative: 11.54 km/s	**Nose radius**	0.19 m	**Peak convective heating**	~2250 W/cm²	**Forebody thickness & mass**	1.2 cm at stagnation point	**Deployment method**	N/A
Trim L/D (specify trim α)	0	**Base area**	0.46 m²	**Peak radiative heating**	~1363 W/cm²	**Ablating Ejected**	Ablated: yes Ejected: no	**Reference diameter / area**	N/A
Control method	Ballistic	**Vehicle mass**	91 kg	**Integrated total heatload**	At stag.pt ~13264 J/cm²	**TPS integration method**	Nose: chopped molded; conical section: tape-wrapped	**Deployment Mach**	N/A
Ballistic co-eff.	190 kg/m²	**Payload mass**	3.60 kg	**Peak heating stag. pressure**	~8.1 atm	**Aftbody material designation**		**Deployment dynamic pressure**	N/A
Peak deceleration	227.7 g	**TPS mass fraction, inc. insul.**	12.9%	**Peak stag. heating rate**	3476 W/cm²	**Aftbody thickness & mass**		**Parachute materials**	N/A

MISSION: PIONEER-VENUS: LARGE PROBE 'SOUNDER'
PLANET: VENUS
LAUNCH: AUG 8, 1978
ENTRY: DEC 9, 1978

MISSION DESCRIPTION: This probe contained 7 experiments, including 1 to measure the atmospheric composition.

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. Parachute deployed at 66.46 km to extract probe from heat shield. Parachute detached from probe at 1076 sec after entry Probe impacted surface (signal ended) 3261 sec. after entry.



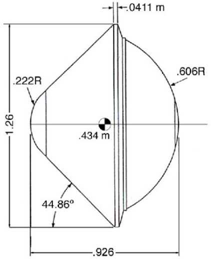
Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Inertial & Relative: -32.37° @ 200 km	**Shape**	Blunt-nosed, 45° half-cone angle	**Velocity at peak heat**	10.82 km/s	**Forebody material designation**	Carbon-phenolic FM 5055	**Type**	(1) Ribless guide surface, 8 gore pilot chute, (2) Conical ribbon, 18 gore main chute
Entry velocity: inertial & relative	Inertial & Relative: 11.54km/s @ 200 km	**Nose radius**	0.36 m	**Peak convective heating**	~1813 W/cm²	**Forebody thickness & mass**	1.60 cm at stagnation point	**Deployment method**	(1) Mortar (2) Pilot chute
Trim L/D (specify trim α)	0	**Base area**	1.59 m²	**Peak radiative heating**	~2468 W/cm²	**Ablating Ejected**	Ablated: yes Ejected: yes	**Reference diameter / area**	(1) 0.76 m dia. (CdA=0.37 m²) (2) 4.94 m dia. (CdA=10.4 m²)
Control method	Ballistic	**Vehicle mass**	316.483 kg	**Integrated total heatload**	At stag.pt ~11305 J/cm²	**TPS integration method**	Nose: chopped molded; conical section: tape-wrapped	**Deployment Mach**	~0.82
Ballistic co-eff.	189.7 kg/m²	**Payload mass**	Science instr. 29.15 kg (9.2%)	**Peak heating stag. pressure**	~10.2 atm	**Aftbody material designation**		**Deployment dynamic pressure**	~3287 pa
Peak deceleration	286.4 g	**TPS mass fraction incinsu**	Forebody: 8.83% Aft cover:1.52%	**Peak stag. heating rate**	4145 W/cm	**Aftbody thickness & mass**		**Parachute materials**	(1) Dacron 1.25 oz/yd² (2) Dacron 2.25 oz/yd²

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.

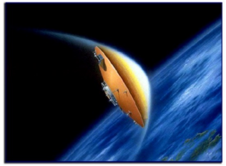
INSTRUMENTATION: Forebody TPS: ablation recession gauges. Afterbody TPS: thermocouples in the nylon phenolic. Galileo was the most difficult entry in the history of space exportation. Attempts to model Galileo's entry are little more than educated guesses with many phenomena poorly understood.

NOTES: Reported CG estimates varied widely. "Blockage" refers to reduction in outer wall heating due to ablation effects.



Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Inertial: -6.65° Relative: -8.41° @ 450 km	**Shape**	Blunt-nosed 44.86° half-cone angle	**Velocity at peak heat**	39.4 km/s	**Forebody material designation**	Carbon-phenolic	**Type**	(1) Pilot: 20° conic ribbon (2) Main: 20° conic ribbon
Entry velocity: inertial & relative	Inertial: 59.83 km/s Relative: 47.41 km/s	**Nose radius**	0.222 m	**Peak convective heating**		**Forebody thickness & mass**	14.6 cm at stagnation	**Deployment method**	(1) Mortar launched with aft cover (2) Pilot parachute
Trim L/D (specify trim α)	0	**Base area**	1.26 m²	**Peak radiative heating**	~38055 W/cm² [unblocked] ~16272 W/cm² [blocked]	**Ablating Ejected**	Ablated: yes Ejected: yes	**Reference diameter / area**	(1) 1.14 m dia. (CdA=0.51 m²) (2) 3.8 m dia. (CdA=5.46 m²)
Control method	Ballistic	**Vehicle mass**	At entry: 338.93 kg	**Integrated total heatload**	~210826 J/cm² with ablation	**TPS integration method**	Nose: chopped molded; conical section: tape-wrapped	**Deployment Mach**	g-switch malfunctioned; chute deployed at 16.6 km above one bar altitude
Ballistic co-eff.	~267.6 kg/m²	**Payload mass**	Science 8.3%	**PH stag. pressure**	7.55 atm	**Aftbody material designation**	Phenolic-nylon	**Deployment dynamic pressure**	See above
Peak deceleration	~228 g	**TPS mass fraction, inc. insul.**	Forebody: 45.4% Afterbody: 5%	**Peak stag. heating rate**	16858 W/cm² [unblocked] 3286 W/cm² [blocked]	**Aftbody thickness & mass**		**Parachute materials**	Dacron

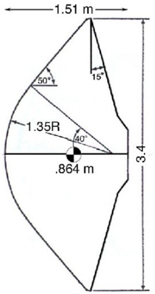
MISSION: OREX
PLANET: EARTH RETURN
LAUNCH: FEB 4, 1994
ENTRY: FEB 4, 1994



MISSION DESCRIPTION: To collect information on the design of a reentry vehicle to support Japanese unmanned space shuttle HOPE.

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

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



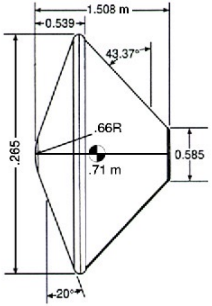
Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Relative -3.17°	**Shape**	50° sphere-cone	**Velocity at peak heat**	6.4 km/s	**Forebody material designation**	Si Coated C-C for nose	**Type**	N/A
Entry velocity: inertial & relative	Inertial: 7.8 km/s Relative: 7.43 km/s	**Nose radius**	1.35 m	**Peak convective heating**	51 W/cm²	**Forebody thickness & mass**	4 cm	**Deployment method**	N/A
Trim L/D (specify trim α)	0	**Base area**	9.08 m²	**Peak radiative heating**	0	**Ablating Ejected**	Ablated: no Ejected: no	**Reference diameter / area**	N/A
Control method	RCS	**Vehicle mass**	761 kg at entry	**Integrated total heatload**		**TPS integration method**	Tiled	**Deployment Mach**	N/A
Ballistic co-eff.	56 kg/m²	**Payload mass**	N/A	**PH stag. pressure**	0.078 atm	**Aftbody material designation**		**Deployment dynamic pressure**	N/A
Peak deceleration		**TPS mass fraction, inc. insul.**	N/A	**Peak stag. heating rate**	51 W/cm²	**Aftbody thickness & mass**		**Parachute materials**	N/A

MISSION: MARS PATHFINDER
PLANET: MARS
LAUNCH: DEC 4, 1996
ENTRY: JUNE 4, 1997

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

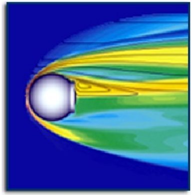
INSTRUMENTATION: TPS instrumented with thermocouples only
Rover called "Sojourner".

NOTES: Spin stabilized.



Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Inertial -14.06° @ 130.86 km	**Shape**	70° sphere-cone	**Velocity at peak heat**	Relative: 6.62 km/s	**Forebody material designation**	SLA-561 V	**Type**	DGB
Entry velocity: inertial & relative	Inertial: 7.26 km/s Relative: 7.48 km/s	**Nose radius**	0.66 m	**Peak convective heating**	100.69 W/cm²	**Forebody thickness & mass**	1.9 cm	**Deployment method**	Mortar fired
Trim L/D (specify trim α)	Ballistic (0° average)	**Base area**	5.51 m²	**Peak radiative heating**	~5.27 W/cm² (with ablation)	**Ablating Ejected**	Ablated: yes Ejected: yes	**Reference diameter / area**	12.7 m
Control method	Ballistic	**Vehicle mass**	At entry: 585.3 kg	**Integrated total heatload**	~3834 J/cm² with ablation	**TPS integration method**	Honeycomb bonded to substructure; cells filled with ablative compound	**Deployment Mach**	1.71
Ballistic co-eff.	At peak dyn. p.: ~61.5 kg/m²	**Payload mass**	N/A	**PH stag. pressure**	~0.19 atm	**Aftbody material designation**	SLA-561S	**Deployment dynamic pressure**	588 Pa
Peak deceleration	16 g	**TPS mass fraction, inc. insul.**	Forebody 6.2% Backshell 2%	**Peak stag. heating rate**	105.96 W/cm²	**Aftbody thickness & mass**	1.27 cm	**Parachute materials**	Nylon, polyester, Kevlar

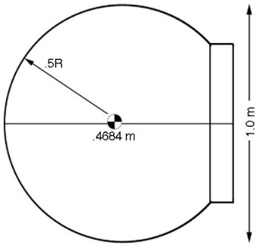
MISSION: MIRKA
PLANET: EARTH
LAUNCH: NOV 9, 1997
ENTRY: NOV 23, 1997



MISSION DESCRIPTION: To qualify a reentry heatshield concept, to assess and validate relevant gas-surface-interactions models, and to assess tumbling processes with scientific and engineering experiments conducted by German researchers.

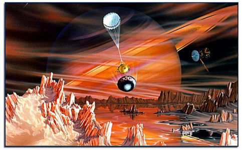
INSTRUMENTATION: 3 acceleration sensors, 3 angular rate sensors, 24 thermocouples, RAFLEX (pressure, temperature & heat flux sensors) and PYREX (pyrometric temperature measurements).

NOTES: CFRP: Carbon Fiber Reinforced Plastics. SPA: Surface Protected Ablator. This was the first successful Western European reentry mission.



Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Relative: -2.51°	**Shape**	Spherical 1 m diameter	**Velocity at peak heat**	6.51 km/s	**Forebody material designation**	CFRP: carbon fiber reinforced plastics SPA: surface protected ablator and fiber ceramic cover	**Type**	unknown
Entry velocity: inertial & relative	Inertial: separation Velocity: 7.3 km/s Relative: 7.6 km/s at 120 km	**Nose radius**	0.5 m	**Peak convective heating**	120 W/cm^2	**Forebody thickness & mass**	Front: 3 cm Back: 2 cm	**Deployment method**	
Trim L/D (specify trim α)	0	**Base area**	0.785 m^2	**Peak radiative heating**	0	**Ablating Ejected**	Ablated: yes Ejected: no	**Reference diameter / area**	
Control method	Ballistic	**Vehicle mass**	154 kg	**Integrated total heatload**	12000 J/cm^2	**TPS integration method**		**Deployment Mach**	
Ballistic co-eff.	214 kg/m^3	**Payload mass**	N/A	**PH stag. pressure**	0.178 atm	**Aftbody material designation**		**Deployment dynamic pressure**	
Peak deceleration		**TPS mass fraction, inc. insul.**	36%	**Peak stag. heating rate**	Peak: 120 W/cm^2	**Aftbody thickness & mass**		**Parachute materials**	

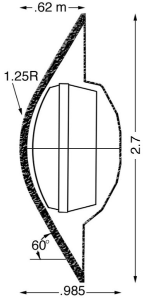
MISSION: HUYGENS
PLANET: TITAN
(A moon of Saturn)
LAUNCH: OCT 15, 1997
ENTRY: JAN 14, 2005



MISSION DESCRIPTION: To explore the atmosphere of Titan.

INSTRUMENTATION: No aeroheating 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.



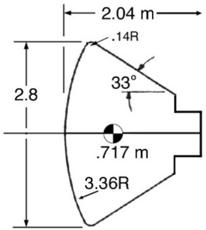
Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Inertial: -65.5° Relative: -65.4°	**Shape**	60° sphere-cone	**Velocity at peak heat**	~5.1 km/s	**Forebody material designation**	AQ60/I	**Type**	(1) Pilot: DGB (2) Main: DGB (3) Descent: DGB
Entry velocity: inertial & relative	Inertial: 6.0 km/s @ 1270 km Relative: 6.0 km/s	**Nose radius**	1.25 m	**Peak convective heating**	~29.3 W/cm²	**Forebody thickness & mass**	At stag: 17.4 mm On flank:18.2 mm 39 kg TPS, 76 kg w/ struct.	**Deployment method**	(1) Mortar (2) Pilot (3) Main
Trim L/D (specify trim α)	0	**Base area**	5.73 m²	**Peak radiative heating**	~0 W/cm²	**Ablating Ejected**	Ablated: yes Ejected: yes	**Reference diameter / area**	(1) 2.59 m dia. (2) 8.31 m dia. (3) 3.03 m dia.
Control method	Ballistic	**Vehicle mass**	320 kg	**Integrated total heatload**	~1397 J/cm²	**TPS integration method**	Tiled	**Deployment Mach**	(1) 1.46 (2) 1.36 (3) 0.14
Ballistic co-eff.	34.5-37.5 kg/m²	**Payload mass**	44 kg	**PH stag. pressure**	0.1 atm	**Aftbody material designation**	Prosial	**Deployment dynamic pressure**	(1) 309 Pa (2) 275 Pa (3) 10 Pa
Peak deceleration	12.36 g	**TPS mass fraction, inc. insul.**	Forebody: 12.2% Aft: 1.64%	**Peak stag. heating rate**	~29.3 W/cm² (140W/cm² design)	**Aftbody thickness & mass**	0.03-0.31 cm, 5.2 kg TPS, 17 kg w/ struct.	**Parachute materials**	Nylon fabric Kevlar structurals

MISSION: ARD 'Atmospheric Reentry Demonstrator'
PLANET: EARTH
LAUNCH: NOV 21, 1998
ENTRY: NOV 21, 1998

MISSION DESCRIPTION: To undertake a complete space flight cycle for ESA, with emphasis on reentry technologies.

INSTRUMENTATION: The capsule afterbody was instrumented with 7 surfaces 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).



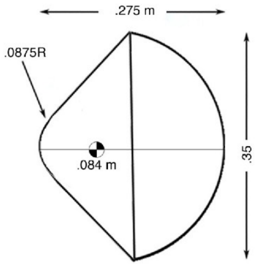
Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	-2.6°	**Shape**	Apollo-like capsule, 33° cone	**Velocity at peak heat**	7.2 km/s	**Forebody material designation**	Aleastrasil	**Type**	(1) Extraction parachute (2) drogue parachute (3) 3 ringsail main parachutes
Entry velocity: Inertial & Relative	Inertial: 7.86 km/s Relative: 7.45 km/s	**Nose radius**	3.36 m	**Peak convective heating**	120 W/cm²	**Forebody thickness & mass**	40-65 mm	**Deployment Method**	(1) Mortar (2) Extraction parachute (3) Drogue parachute
Trim L/D (specify trim α)	-21.2°	**Base area**	6.15 m²	**Peak radiative heating**	~0 W/cm²	**Ablating Ejected**	Ablated: yes Ejected: no	**Reference diameter / area**	(1) 0.9 m dia. (2) 5.8 m dia. (3) 22.9 m dia.
Control method	RCS: 7 thrusters	**Vehicle mass**	2715 kg (inc.1017 kg front heat shield)	**Integrated total heatload**	~24000 J/cm²	**TPS integration method**	Tiled	**Deployment Mach**	~0.8
Ballistic co-eff.	~347 kg/m²	**Payload mass**	N/A	**PH stag. pressure**	0.22 atm	**Aftbody material designation**	Norcoat 622-50FI (See note)	**Deployment dynamic pressure**	
Peak deceleration	~11 g	**TPS mass fraction, inc. insul.**	23% (626 kg TPS)	**Peak stag. heating rate**	120 W/cm²	**Aftbody thickness & mass**	19 mm	**Parachute materials**	

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.

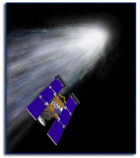
INSTRUMENTATION:

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.



Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Inertial -13.25° @128 km	**Shape**	45° sphere-cone, spherical aft	**Velocity at peak heat**	5.94 km/s	**Forebody material designation**	SIRCA-SPLIT	**Type**	N/A
Entry velocity: inertial & relative	Relative: 6.9 km/s	**Nose radius**	0.0875 m	**Peak convective heating**	194 W/cm²	**Forebody thickness & mass**	~1 cm	**Deployment method**	N/A
Trim L/D (specify trim α)	0	**Base area**	0.096 m²	**Peak radiative heating**	N/A	**Ablating Ejected**	Ablated: Ejected: no	**Reference diameter / area**	N/A
Control method	Ballistic	**Vehicle mass**	3.67 kg	**Integrated total heatload**	8712 J/cm²	**TPS integration method**	Monolithic	**Deployment Mach**	N/A
Ballistic co-eff.	36.2 kg/m²	**Payload mass**	N/A	**PH stag. pressure**		**Aftbody material designation**	FRCI: Fibrous refractory composite insulation	**Deployment dynamic pressure**	N/A
Peak deceleration	12.4 g	**TPS mass fraction, inc. insul.**	N/A	**Peak stag. heating rate**	194 W/cm²	**Aftbody thickness & mass**		**Parachute materials**	N/A

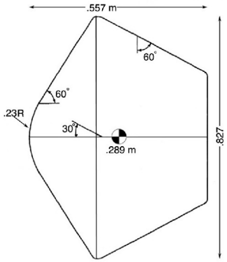
MISSION: **STARDUST**
PLANET: **EARTH RETURN**
LAUNCH: **FEB 7, 1999**
ENTRY: **JAN 15, 2006**



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

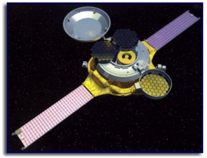
INSTRUMENTATION: Stardust has the highest successful Earth return velocity. Most heating models breakdown for Stardust. Classic Fay-Riddell is not trustworthy for Stardust.

NOTES: The rendezvous with Wild 2 occurred on Jan 2, 2004. The Stardust capsule made a successful return to Earth on Jan 15, 2006. Engineering methods and CFD disagree for heating rates. Traj. gives at stag. point 762 W/cm² peak total heat rate and 122 W/cm² peak radiative heat rate. Total heat load is 20978 J/cm².



Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	-8.23° @ 134.4 km	**Shape**	Blunt-nosed 60° half-angle cone	**Velocity at peak heat**	11.1 km/s	**Forebody material designation**	PICA-15	**Type**	(1) Pilot: DGB (2) Main: Triconical
Entry velocity: inertial & relative	Inertial: 12.8 km/s Relative: 12.45 km/s	**Nose radius**	0.23 m	**Peak Convective heating**	~817 W/cm²	**Forebody thickness & mass**	5.82 cm	**Deployment method**	(1) Mortar (2) Pilot pulled
Trim L/D (specify trim α)	0	**Base area**	0.52 m², 0.50 m² (ablated)	**Peak Radiative heating**	~71 W/cm²	**Ablating Ejected**	Ablated: yes Ejected: no	**Reference diameter / area**	(1) 0.83 m dia. (2) 7.3 m dia.
Control method	Ballistic, spin-stabilized at 14.5 rpm	**Vehicle mass**	45.8 kg	**Integrated total heatload**	~26210 J/cm²	**TPS integration method**	PICA: single-piece, direct bonded to substructure with HT-424	**Deployment Mach**	(1) 1.4m +/- 0.3
Ballistic co-eff.	60.0 kg/m² 60.4 kg/m² (ablated)	**Payload mass**	N/A	**PH stag. pressure**	0.22 atm	**Aftbody material designation**	SLA-561V	**Deployment dynamic pressure**	(1) 713 Pa
Peak deceleration	32.89 g	**TPS mass fraction, inc. insul.**	22%	**Peak stag. heating rate**	~880 W/cm²	**Aftbody thickness & mass**	Design: 1.397 cm	**Parachute materials**	Canopy: nylon, Kevlar suspension lines

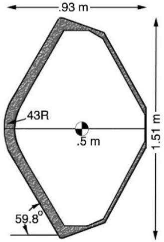
MISSION: GENESIS
PLANET: EARTH RETURN
LAUNCH: SEP 8, 2001
ENTRY: SEP 8, 2004



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.



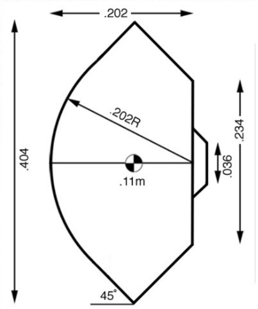
Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	-8°	**Shape**	59.81°	**Velocity at peak heat**	9.2 km/s	**Forebody material designation**	Carbon-carbon sheet over FiberForm®	**Type**	(1) Pilot: DGB (2) Main: Parafoil
Entry velocity: inertial & relative	Inertial: 11.0 km/s Relative: 10.8 km/s	**Nose radius**	0.43 m	**Peak convective heating**	670 W/cm²	**Forebody thickness & mass**	3.8 cm C-C sheet; 2.2 cm carbon FiberForm®	**Deployment Method**	(1) Mortar (2) Pilot parachute
Trim L/D (specify trim α)	0	**Base area**	1.78 m²	**Peak radiative heating**	30 W/cm²	**Ablating Ejected**	Ablated: yes Ejected: no	**Reference Diameter / Area**	(1) 2.07 m dia. (2) 325 m² area
Control method	Spin-stabilized aero-ballistic	**Vehicle mass**	210 kg	**Integrated total heatload**	16600 J/cm²	**TPS integration method**		**Deployment Mach**	(2) ~1.4
Ballistic co-eff.	80 kg/m³	**Payload mass**	N/A	**PH stag. pressure**	N/A	**Aftbody material designation**	SLA-561V	**Deployment dynamic pressure**	N/A
Peak deceleration	~25.7 g	**TPS mass fraction, inc. insul.**	~18%	**Peak stag. heating rate**	700 W/cm²	**Aftbody thickness & mass**		**Parachute materials**	nylon fabric Kevlar structural

MISSION: HAYABUSA
PLANET: EARTH RETURN
LAUNCH: MAY 9, 2003
ENTRY: JUL 13, 2007

MISSION DESCRIPTION: To collect samples from asteroid Itokawa (1998SF36) and return to Earth.

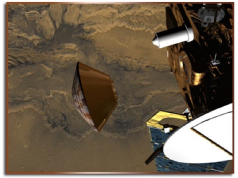
INSTRUMENTATION: A one-axis accelerometer for parachute deployment.

NOTES: The mission's name was changed from MUSES-C.



Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	-12.79° @199.97 km	**Shape**	45° sphere-cone	**Velocity at peak heat**	10.61 km/s	**Forebody material designation**	Carbon-phenolic	**Type**	Cross-type
Entry velocity: inertial & relative	Inertial: 12.04 km/s Relative: 11.65 km/s	**Nose radius**	0.202 m	**Peak convective heating**	1050 W/cm²	**Forebody thickness & mass**	3.0 cm	**Deployment method**	Mortar fired
Trim L/D (specify trim α)	0	**Base area**	0.128 m²	**Peak radiative heating**	264 W/cm²	**Ablating Ejected**	Ablated: yes Ejected: yes	**Reference diameter / area**	2.8 m²
Control method	none	**Vehicle mass**	18 kg	**Integrated total heatload**	23051 J/cm²	**TPS integration method**	Segmented	**Deployment Mach**	0.8
Ballistic co-eff.	133.72 kg/m³	**Payload mass**	1.04 kg	**PH stag. pressure**	0.63 atm	**Aftbody material designation**	Carbon-phenolic	**Deployment dynamic Pressure**	
Peak deceleration	~53.36 g	**TPS mass fraction, inc. insul.**	43%	**Peak stag. heating rate**	1314 W/cm²	**Aftbody thickness & mass**	2 cm	**Parachute materials**	Canopy: polyester

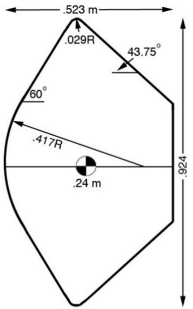
MISSION: BEAGLE 2
PLANET: MARS
LAUNCH: JUN 2, 2003
ENTRY: DEC 25, 2003



MISSION DESCRIPTION: To develop a low-cost, low-mass system for placing an exobiology science payload on Mars. Beagle 2 was transported by the European Space Agency's 2003 Mars Express mission.

INSTRUMENTATION: No TPS instrumentation: axial accelerometers only.

NOTES: Beagle 2 landed on Mars but did not make radio contact and was never operative.

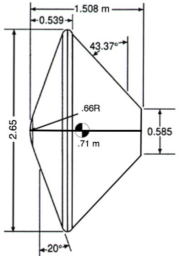


Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Inertial: -15.8°	**Shape**	43.75° truncated conical backshell 60° sphere-cone front shield	**Velocity at peak heat**	Relative: 4.70 km/s	**Forebody material designation**	Norcoat-Liege (EADS)	**Type**	(1) DGB pilot (2) Ringsail main
Entry velocity: inertial & relative	Inertial: 5.63 km/s Relative: 5.40 km/s	**Nose radius**	0.417 m	**Peak convective heating**	72.11 W/cm²	**Forebody thickness & mass**	8 mm 3.9 kg	**Deployment method**	(1) Mortar (2) Pilot parachute
Trim L/D (specify trim α)	Ballistic (2° average)	**Base area**	0.67 m²	**Peak radiative heating**	0.17 W/cm²	**Ablating Ejected**	Ablated: yes Ejected: yes	**Reference diameter / Area**	(1) 3.2 m dia. (2) 10 m dia.
Control method	Ballistic spin-stabilized at 14.2 rpm	**Vehicle mass**	Entry: 68.84 kg	**Integrated total heatload**	2449 J/cm²	**TPS integration method**	Tiled	**Deployment Mach**	(1) 1.5
Ballistic co-eff.	Peak heat flux: 69.9 kg/m²	**Payload mass**	11.4 kg (science) (33.2 kg landed)	**PH stag. pressure**	0.18 atm	**Aftbody material designation**	Norcoat-Liege (EADS)	**Deployment dynamic pressure**	(2) 730-750 Pa
Peak deceleration		**TPS mass fraction, inc. insul.**	Forebody: 9.2% Back shell: 15.2%	**Peak stag. heating rate**	72.28 W/cm²	**Aftbody thickness & mass**	3 to 6 mm 2kg	**Parachute materials**	Nylon, Kevlar

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.

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 like 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.



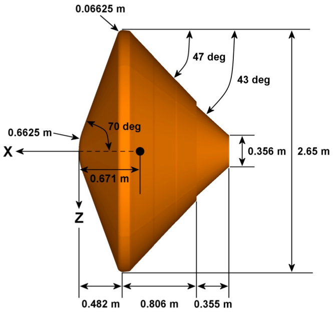
Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	-10.75° @ 126.799 km	**Shape**	70° sphere-cone	**Velocity at peak heat**	~4.96 km/sec	**Forebody material designation**	SLA-561V (SLA-561S for backshell)	**Type**	Single DGB
Entry velocity: inertial & relative	Inertial: 5.78 km/sec Relative: 5.39 km/sec	**Nose radius**	0.66 m	**Peak convective heating**	~37.72 W/cm²	**Forebody thickness & mass**	1.57 cm	**Deployment method**	Mortar
Trim L/D (specify trim α)	0	**Base area**	5.499 m²	**Peak radiative heating**	~0	**Ablating Ejected**	Ablated: yes Ejected: yes	**Reference diameter / area**	14.1 m dia.
Control method	Ballistic, spin-stabilized	**Vehicle mass**	832.2 kg	**Integrated total heatload**	~3064.45 J/cm^2	**TPS integration method**	Honeycomb bonded to substructure; cells filled with ablative compound	**Deployment Mach**	1.77
Ballistic co-eff.	~88.96 kg/m²	**Payload mass**	~525 kg (landed mass, rover+lander)	**PH stag. pressure**	0.08 atm	**Aftbody material designation**	SLA-561S for backshell, backshell interface plate (BIP): SIRCA	**Deployment dynamic Pressure**	765±77 Pa
Peak deceleration	~4.78 g	**TPS mass fraction, inc. insul.**	Forebody: (TPS only) 3.6% Back shell: (TPS only) 2%	**Peak stag. heating rate**	~37.72 W/cm^2	**Aftbody thickness & mass**	0.5 cm (CDR) 10.4 kg (CDR CBE)	**Parachute materials**	Disk: nylon fabric Band: polyester fabric Kevlar structural

MISSION: PHOENIX
PLANET: MARS
LAUNCH: AUG 4, 2011
ENTRY: MAY 5, 2008

MISSION DESCRIPTION: First NASA Scout Mission. Goals: (1) to study the history of water in the Martian artic and (2) search for evidence of habitable zone and assess the biological potential of the ice-soil boundary.

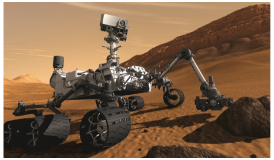
INSTRUMENTATION: 24 thermocouples, MEADS (Mars Entry Atmospheric Data System) for temperature and isotherm tracking.

NOTES: Entry vehicle originally designed for cancelled Mars Surveyor 2001.



Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	[-13.°]	**Shape**	2.65 m diameter, 70 deg. sphere cone	**Velocity at peak heat**	[4.743 km/s]	**Forebody Material designation**	SLA-561V	**Type**	Viking-type DGB
Entry velocity: Inertial & Relative	Inertial: 5.6 km/s	**Nose radius**	Rn=0.66 m	**Peak convective heating**	[4.8 W/cm²]	**Forebody Thickness & mass**		**Deployment Method**	Mortar
Trim L/D (specify trim α)	0	**Base area**	0.0995 m²	**Peak radiative heating**		**Ablating Ejected**		**Reference Diameter / Area**	11.8 m dia.
Control method	Non-spinning passive	**Vehicle mass**	602 kg	**Integrated total heatload**	[2301 J/cm²]	**TPS Integration method**		**Deployment Mach**	1.74
Ballistic co-eff.	65 kg/m²	**Payload mass**	59 kg	**PH stag. pressure**		**Aftbody material designation**	SLA-561S on cone, SLA-561V on parachute cover	**Deployment dynamic pressure**	489.3 Pa
Peak deceleration	[9.3 Earth G's]	**TPS mass fraction, inc. insul.**		**Peak stag. heating rate**		**Aftbody thickness & mass**		**Parachute materials**	Nylon canopy, Kevlar structural members

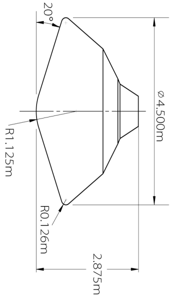
MISSION: MARS SCIENCE LABORATORY (MSL)
PLANET: MARS
LAUNCH: NOV 26, 2011
ENTRY: AUG 6, 2012



MISSION DESCRIPTION: To determine if Mars was ever able to support microbial life.

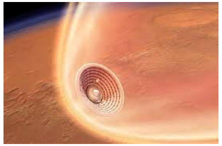
INSTRUMENTATION: 24 thermocouples, MEADS (Mars Entry Atmospheric Data System) for temperature and isotherm tracking.

NOTES:



Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	-16°	**Shape**	70° sphere-cone	**Velocity at peak heat**	5.33 km/s	**Forebody Material designation**	PICA	**Type**	DGB
Entry velocity: Inertial & Relative	Inertial: 6.08 km/s Relative: 5.8 km/s	**Nose radius**	1.125 m	**Peak convective heating**	[197 W/cm²]	**Forebody Thickness & mass**	[3.18 cm]	**Deployment Method**	Mortar fired
Trim L/D (specify trim α)	0.24	**Base area**	15.90 m	**Peak radiative heating**		**Ablating Ejected**	Ablated: yes Ejected: yes	**Reference Diameter / Area**	21.35 m
Control method	RCS: 8 thrusters ballast ejection	**Vehicle mass**	3257 kg	**Integrated total heatload**	[5477 J/cm²]	**TPS Integration method**	PICA: tiled, direct bonded to substructure	**Deployment Mach**	1.7
Ballistic co-eff.	[146 kg/m²]	**Payload mass**	75 kg	**PH stag. pressure**		**Aftbody material designation**	SLA-561V	**Deployment dynamic pressure**	493.6 Pa
Peak deceleration	~9.7 g	**TPS mass fraction, inc. insul.**		**Peak stag. heating rate**		**Aftbody thickness & mass**	[1.27 cm]	**Parachute materials**	Canopy: nylon, Suspension lines: Technora T221 and Kevlar 29

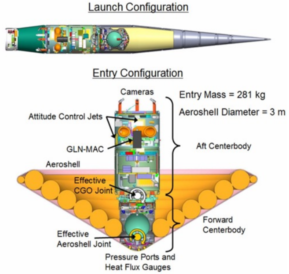
MISSION: INFLATABLE REENTRY VEHICLE EXPERIMENT-3 (IRVE-3)
PLANET: EARTH (SUBORBITAL)
LAUNCH: JUL 23, 2012
ENTRY: JUL 23, 2012



MISSION DESCRIPTION: To advance the hypersonic inflatable aerodynamic decelerator (HIAD) technology, reach higher than 12 W/cm^2 cold-wall heat flux on the flexible TPS, and generate aerodynamic lift, with the potential for guided entry applications.

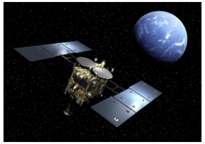
INSTRUMENTATION:

NOTES: IRVE-3 is NASA's second successful flight test of Hypersonic Inflatable Aerodynamic Decelerator (HIAD).



Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	-74°	**Shape**	60° half angle sphere-cone	**Velocity at peak heat**	Mach 7.3	**Forebody Material designation**	Nextel BF-20	**Type**	N/A
Entry velocity: inertial & relative	Relative: 2.7 km/s	**Nose radius**	0.191 m	**Peak convective heating**	14 W/cm^2 (cold wall)	**Forebody Thickness & mass**	0.6 cm	**Deployment method**	N/A
Trim L/D (specify trim α)	0.2 (max.) at 16°	**Base area**	7.07 m^2	**Peak radiative heating**	0	**Ablating Ejected**	Flexible	**Reference diameter / area**	N/A
Control method	Cold argon gas pre-entry alignment, roll control during entry. Movable radial mass offset entry.	**Vehicle mass**	281 kg	**Integrated total heatload**	193 J/cm^2 (cold wall)	**TPS Integration method**	Sewn fabric	**Deployment Mach**	N/A
Ballistic co-eff.	58 kg/m^2	**Payload mass**	N/A	**PH stag. pressure**	1 psia	**Aftbody material designation**	N/A	**Deployment dynamic pressure**	N/A
Peak deceleration	20.2 g	**TPS mass fraction, inc. insul.**	0.20	**Peak stag. heating rate**		**Aftbody thickness & mass**	N/A	**Parachute materials**	N/A

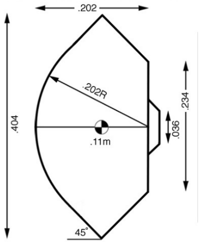
MISSION: HAYABUSA 2
PLANET: EARTH RETURN
LAUNCH: DEC 3, 2014
ENTRY: DEC 5, 2020



MISSION DESCRIPTION: To collect samples from asteroid RYUGU (1999JU3) and return to Earth.

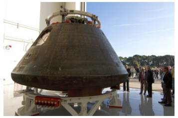
INSTRUMENTATION: A one-axis accelerometer of parachute deployment REMM(Reentry Flight Measurement Module) which measures and records the heatshield temperature, the acceleration and the attitude motion of SRC during the reentry.

NOTES:



Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	-12.06°	**Shape**	45° sphere-cone	**Velocity at peak heat**	~10.5 km/s	**Forebody material designation**	Carbon-phenolic	**Type**	Cross-Type
Entry velocity: inertial & relative	Inertial: 11.84 km/s Relative: 11.58 km/s	**Base radius** **Nose radius**	0.202 m	**Peak convective heating**	~1110 W/cm²	**Forebody thickness & mass**		**Deployment method**	Mortar fired
Trim L/D (specify trim α)	0	**Base area**	0.128 m²	**Peak radiative heating**	~180 W/cm²	**Ablating Ejected**	Ablated: yes Ejected: no	**Reference diameter / area**	2.8 m²
Control method	None	**Vehicle mass**	16.03 kg	**Integrated total heatload**	~27000 J/cm²	**TPS integration method**	Segmented	**Deployment Mach**	Subsonic
Ballistic co-eff.	113.5 kg/m³	**Payload mass**	1.13 kg	**PH stag. pressure**	~0.44 atm	**Aftbody material designation**	Carbon-phenolic	**Deployment dynamic pressure**	< 2kPa
Peak deceleration	46.3 g	**TPS mass fraction, inc. insul.**		**Peak stag. heating rate**		**Aftbody thickness & mass**	2 cm	**Parachute materials**	Canopy: polyester

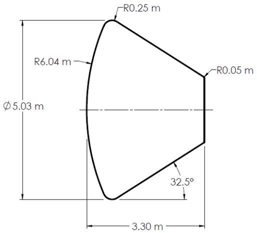
MISSION: EXPLORATION FLIGHT TEST-1
PLANET: EARTH RETURN
LAUNCH: DEC 5, 2014
ENTRY: DEC 5, 2014



MISSION DESCRIPTION: To flight test Orion through two orbits of Earth with observation of radiation stresses and orbit debris environment.

INSTRUMENTATION: 2 broadband radiometers.

NOTES: Aerothermal values are margined.



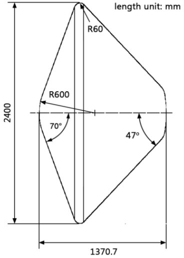
Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	-12.6°	**Shape**	Spherical	**Velocity at peak heat**	~7.53 km/s	**Forebody material designation**	Avcoat	**Type**	(1) Drogue = VPCRibbon 2x (2) Pilot = VPCRibbon 3x (3) Main = Ringsail 3x
Entry velocity: inertial & relative	Inertial: 8.5 km/s Relative: 8.9 km/s	**Nose radius**	6.035 m	**Peak convective heating**	Flown:170 W/cm² [Design: 400W/cm²]	**Forebody thickness & mass**	Var. thick 2.5-4cm ~454 kg	**Deployment method**	(1) Mortar drogue (2) Mortar pilot (3) Pilot main
Trim L/D (specify trim α)	0.25	**Base area**	19.8 m²	**Peak radiative heating**	Flown: 15 W/cm² [Design: 50 W/cm²]	**Ablating Ejected**	Ablated: yes Ejected: no	**Reference diameter / area**	(1) 7.0 m dia. (2) 3.0 m dia. (3) 35.4 m dia.
Control method	RCS Thrusters	**Vehicle mass**	9611 kg	**Integrated total heatload**	~250 MJ/m²	**TPS integration method**	Honeycomb bonded to substructure; cells filled with ablative compound	**Deployment Mach**	(1) 0.42 (2) 0.17
Ballistic co-eff.	360 kg/m^2 (C_D = 1.4 at EI+50 sec.)	**Payload mass**	Minimal	**PH stag. pressure**	~0.56 atm	**Aftbody material designation**	RCG coated AETB-8	**Deployment dynamic pressure**	(1) ~5746 Pa (2) ~1915 Pa
Peak deceleration	~3.2 g	**TPS mass fraction, inc. insul.**	Fore: 4.7% Aft: 1.2%	**Peak stag. heating rate**		**Aftbody thickness & mass**	Var. thick 2.5-4.2 cm ~120 kg	**Parachute materials**	Nylon and Kevlar

MISSION: EXOMARS 2016
PLANET: MARS
LAUNCH: MAR 14, 2016
ENTRY: OCT 19, 2016

MISSION DESCRIPTION: To demonstrate entry, descent, and landing of a payload on the surface of Mars.

INSTRUMENTATION: Front Shield: 4 pressure sensors; 7 thermal plugs (each with 3 thermocouples and 1 thermistor). Back Shell: 3 thermal plugs (each with 2 thermocouples and 1 thermistor); COMARS+ (3 combined sensor heads + one broadband IR radiometer).

NOTES: ExoMars 2016 comprised a trace gas orbiter and the Schiaparelli EDL demonstrator module. An anomaly in the measurement and navigation sequence resulted in Schiaparelli crash-landing on the surface of Mars, but essential telemetry was received during entry and descent.



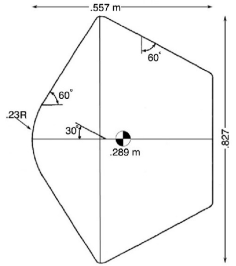
Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	-12.48° @120km	**Shape**	47° truncated conical backshell 70° sphere-cone front shield	**Velocity at peak heat**	~5 km/s	**Forebody material designation**	Norcoat-Liège over Al honeycomb with CFRP skins	**Type**	DGB
Entry velocity: inertial & relative	Inertial: 6.03 km/s Relative: 5.79 km/s	**Nose radius**	0.6 m	**Peak convective heating**	~50 - 70 W/cm²	**Forebody thickness & mass**	12.2 mm (nose) to 15.4 mm (trailing edge) 37 kg	**Deployment method**	Mortar fired
Trim L/D (specify trim α)		**Base area**	4.52 m² (2.4 m dia. heatshield)	**Peak radiative heating**	~9 W/cm²	**Ablating Ejected**	Ablated: yes Ejected: yes	**Reference diameter / area**	12 m dia.
Control method	Ballistic, spin-stabilized at 2.617 rpm	**Vehicle mass**	576.3 kg	**Integrated total heatload**		**TPS integration method**	Tiled	**Deployment Mach**	2.08
Ballistic co-eff.	75.2 kg/m²	**Payload mass**	15.2 kg	**PH stag. pressure**	~0.11 Atm	**Aftbody material designation**	same as forebody	**Deployment dynamic pressure**	779.5
Peak deceleration	8.15 g	**TPS mass fraction, inc. insul.**	0.11	**Peak stag. heating rate**		**Aftbody thickness & mass**	7.6 mm 26.2 kg	**Parachute materials**	Nylon, Kevlar

MISSION: OSIRIS-REX
PLANET: EARTH RETURN
LAUNCH: SEPT 8, 2016
ENTRY: PLANNED FOR SEPT 24, 2023

MISSION DESCRIPTION: To return and analyze samples from asteroid Bennu (1999RQ36) and return to Earth.

INSTRUMENTATION:

NOTES: The OSIRIS-REx capsule outer geometry and TPS are build-to-print based on the Stardust capsule.

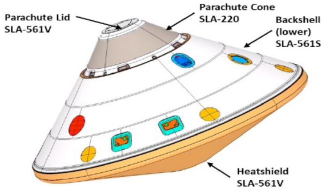


Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	[-8.2°]	**Shape**	Blunt-nosed 60° half-angle once	**Velocity at peak heat**	11.1 km/s	**Forebody material designation**	PICA-15	**Type**	(1) Pilot: DGB (2) Main: Triconical
Entry velocity: inertial & relative	Relative: [12.2 km/s]	**Nose radius**	0.23 m	**Peak convective heating**	[1070 W/cm²]	**Forebody thickness & mass**	5.82 cm	**Deployment method**	(1) Mortar (2) Pilot parachute
Trim L/D (specify trim α)	0	**Base area**	0.52 m²	**Peak radiative heating**	[130 W/cm²]	**Ablating Ejected**	Ablated: yes Ejected: no	**Reference diameter / area**	(1) 0.83 m dia. (2) 7.3 m dia.
Control method	Ballistic, spin-stabilized at 13 rpm	**Vehicle mass**	~46 kg	**Integrated total heatload**	[36000 J/cm²]	**TPS integration method**	PICA: single-piece, direct bonded to substructure with HT-424	**Deployment Mach**	(1) [1.3] (2) [0.12]
Ballistic co-eff.	~71 kg/m²	**Payload mass**	N/A	**PH stag. pressure**	[0.22 atm]	**Aftbody material designation**	SLA-561V	**Deployment dynamic pressure**	(1) ~1350 Pa (2) ~700 Pa
Peak deceleration	~32 g	**TPS mass fraction, inc. insul.**	0.22	**Peak stag. heating rate**	[1200 W/cm²]	**Aftbody thickness & mass**	[1.397 cm]	**Parachute materials**	Canopy: nylon, Kevlar suspension lines

MISSION: MARS InSight
PLANET: MAR
LAUNCH: MAY 5, 2018
ENTRY: SEPT 26, 2018

MISSION DESCRIPTION: Robotic lander to study the deep interior of Mars.

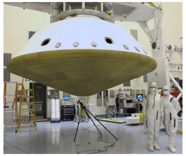
INSTRUMENTATION: SEIS seismometer to measure Mars quakes, HP3 Heat Flow and Physical Properties Package to measure heat flowing out of deep interior, RISE radio science instrument to measure wobble of Mars north pole.



NOTES: Discovery program mission; InSight = Interior Exploration using Seismic Investigations, Geodesy and Heat Transport; EDL system reused design of Phoenix mission augmented for landing during dust storm season; dust on solar panels led to mission termination on December 21, 2022.

Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	-12°	**Shape**	2.65 m diameter, 70° sphere cone	**Velocity at peak heat**	4835.8 m/s	**Forebody material designation**	SLA-561V	**Type**	Viking-type DGB
Entry velocity: inertial & relative	Relative: 5.523 km/s	**Nose radius**	0.66 m	**Peak convective heating**	46 W/cm^2	**Forebody thickness & mass**	1.93 cm & 35.74 kg	**Deployment method**	Mortar
Trim L/D (specify trim α)	0	**Base area**	0.0995 m^2	**Peak radiative heating**	5 W/cm^2 stag. pt.	**Ablating Ejected**	Ablated: yes Ejected: yes	**Reference diameter / area**	11.8 m dia.
Control method	Non-spinning passive	**Vehicle mass**	605.65 kg (wet)	**Integrated total heatload**	2514 J/cm^2	**TPS integration method**	Direct application of flexcore then filler	**Deployment Mach**	1.53
Ballistic co-eff.	65 kg/m^2	**Payload mass**	~50 kg	**PH stag. pressure**	6.38 kPa	**Aftbody material designation**	SLA-561S lower aftbody, SLA-220 parachute cone, SLA-561V on parachute lid	**Deployment dynamic pressure**	546.0 Pa
Peak deceleration	8.13 g	**TPS mass fraction, inc. insul.**	0.85	**Peak stag. heating rate**	~7 W/cm^2	**Aftbody thickness & mass**	0.61 cm lower aftbody 12.46 kg, 1.22 cm parachute cone 3.07 kg, 0.89 cm parachute lid 0.12 kg	**Parachute materials**	Nylon canopy, Kevlar structural members

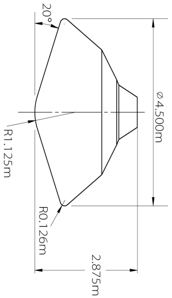
MISSION: MARS2020
PLANET: MARS
LAUNCH: JUL 30, 2020
ENTRY: FEB 18, 2021



MISSION DESCRIPTION: Seek signs of ancient life and collect samples of rock and regolith (broken rock from soil) for possible return to Earth.

INSTRUMENTATION: MEADS (Mars Entry Atmospheric Data System): 1 hypersonic heatshield pressure transducer, 6 supersonic heatshield pressure transducers, 1 low pressure transducer on backshell. MISP (MEDLI2 Instrumented Sensor Plugs): 11 PICA heatshield plugs with 1-3 embedded TCs, 6 SLA-561V plugs on backshell with 1-2 embedded TCs, and 3 direct heat flux sensing elements on backshell (2 total heat flux gauges and 1 radiometer).

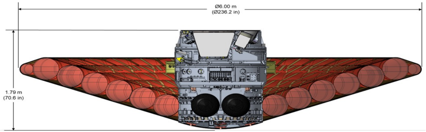
NOTES:



Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	Relative: -16.18°	**Shape**	70° sphere-cone	**Velocity at peak heat (PH)**	4880 m/s	**Forebody material designation**	PICA	**Type**	DGB
Entry velocity: inertial & relative	Relative: 5.33 km/s @ 128.2 km	**Nose radius**	1 m	**Peak convective heating**	68.4 W/cm²	**Forebody thickness & mass**	[3.18 cm] [212 kg]	**Deployment method**	Mortar fired
Trim L/D (specify trim α)	0.248 at -16.71°	**Base area**	15.9 m²	**Peak radiative heating**	~0 W/cm²	**Ablating Ejected**	Ablated: yes Ejected: yes	**Reference diameter / area**	21.5 m
Control method	RCS: 8 thrusters ballast ejection	**Vehicle mass**	3317.3 kg	**Integrated total heatload**	1672.5 J/cm²	**TPS integration method**	PICA: tiled, direct bonded to substructure	**Deployment Mach**	1.81
Ballistic co-eff.	143.2 kg/m²	**Payload mass**	1022.8 kg	**PH stag. pressure**	24 kPa	**Aftbody material designation**	SLA-561V	**Deployment dynamic pressure**	519.6 Pa
Peak deceleration	10.73 g	**TPS mass fraction, inc. insul.**	Fore: [6.4%] Aft: [1.9%]	**Peak stag. heating rate**	68.4 W/cm²	**Aftbody thickness & mass**	[1.27 cm] [64 kg]	**Parachute materials**	Canopy: nylon, suspension lines: Technora T221 and Kevlar 29

MISSION: LOFTID
PLANET: Earth
LAUNCH: Nov 10, 2022
ENTRY: Nov 10, 2022

MISSION DESCRIPTION: Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID). Technology demonstration mission to advance hypersonic inflatable aerodynamic decelerator (HIAD) technology by testing the Gen-2 inflatable structure and flexible thermal protection system (FTPS).



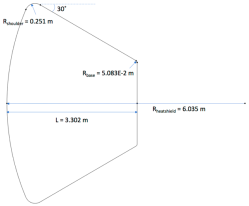
INSTRUMENTATION: 58 FTPS thermocouples, 24 inflatable structure thermocouples, 3 fiber optic sensing systems (FOSS), 4 total heat flux sensors, 1 radiometer, 5 nose pressure transducers, 12 loadcell pins, 7 torus pressure transducers, 6 inflation system pressure transducers, 6 inflation system pressure transducers, 3 inflation system RTDs, 1 inflation system flow meter, 2 hot film anemometers, 6 visual cameras, 12 infrared cameras, 1 up-look camera.

NOTES:

Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	[-2.3°]	**Shape**	70° sphere-cone stacked torus	**Velocity at peak heat (PH)**	[7.02 km/s]	**Forebody material designation**	FTPS: Silicon carbide outer fabric, carbon felt/pyrogel insulation, TZL gas barrier	**Type**	(1) Pilot: 16 .6 ft Cruciform (2) Main: 94 ft Ring Sail
Entry velocity: inertial & relative	Relative: [8.0 km/s]	**Nose radius**	1.715 m	**Peak convective heating**	30 W/cm²	**Forebody thickness & mass**	0.5" / 114 kg	**Deployment method**	(1) Mortar (2) Pilot
Trim L/D (specify trim α)	0	**Base area**	28.27 m²	**Peak radiative heating**	2 W/cm²	**Ablating Ejected**	Ablative: No Ejected: No	**Reference diameter / area**	(1) 16.6 ft (2) 94 ft
Control method	Ballistic, spin-stabilized at 3 rpm	**Vehicle mass**	1101 kg	**Integrated total heatload**	2.7 kJ/cm^2	**TPS integration method**	Sewn Fabric	**Deployment Mach**	(1) 0.1 (2) 0.1
Ballistic co-eff.	22 kg/m²	**Payload mass**	N/A	**PH stag. pressure**	~0.4 psia	**Aftbody material designation**	N/A	**Deployment dynamic pressure**	[415 Pa]
Peak deceleration	~9 g	**TPS mass fraction, inc. insul.**	0.17 (aeroshell)	**Peak stag. heating rate**	[0.66 W/cm^2 (cold wall)]	**Aftbody thickness & mass**	N/A	**Parachute materials**	Nylon, Kevlar

MISSION: Artemis I
PLANET: Earth
LAUNCH: Nov 15, 2022
ENTRY: Dec 11, 2022

MISSION DESCRIPTION: Artemis I is the first in a series of increasingly complex missions that will enable human exploration to the Moon and Mars.
INSTRUMENTATION: Thermocouples (multiple locations and in-depth), Pressure Transducers, and Radiometers.
NOTES: Data is mostly from internal documentation.



Trajectory		Geometry		Aero/thermal		TPS		Parachutes	
Entry angle	-5.66°	**Shape**	Capsule	**Velocity at peak heat (PH)**	~34,200 ft/2	**Forebody material designation**	Avcoat	**Type**	Ringsail
Entry velocity: inertial & relative	Inertial: 36062.66 ft/s Relative: 35974.97 ft/s	**Nose radius**	6.04 m	**Peak convective heating**	~175 BTU/ft^2/s	**Forebody thickness & mass**	Varied thickness ~223 lbm	**Deployment method**	Mortar
Trim L/D (specify trim α)	[0.27 at 162°]	**Base area**	3.33 m²	**Peak radiative heating**	~180 BTU/ft^2/s	**Ablating Ejected**	Ablator	**Reference diameter / area**	FBC chutes (3) - 7 ft Drogues (2) - 23 ft, 400 ft^2 Pilot (2) - 11 ft, 95 ft^2 Mains (4) - 116 ft, 10,500 ft^2
Control method	12 RCS Jets	**Vehicle mass**	~20575 lbm	**Integrated total heatload**	~70000 Btu/ft^2	**TPS integration method**	Tiled	**Deployment Mach**	~0.42 (FBC chutes) ~0.39 (drogues) ~0.17 (pilots/mains)
Ballistic co-eff.	~68.33 lbf/ft²	**Payload mass**		**PH stag. pressure**	~22,000 lb/ft^2	**Aftbody material designation**	AETB-8	**Deployment dynamic pressure**	~3600 lb (FBC chutes) ~3500 lb (drogues) ~1000 lb (pilots/mains)
Peak deceleration	~13.4 g	**TPS mass fraction, inc. insul.**	Heatshield: ~27%	**Peak stag. heating rate**	qtot ~20 BTU/ft^2/s, qconv ~15 BTU/ft^2/s, qrad ~6 BTU/ft^2/s	**Aftbody thickness & mass**	Varied thickness 1.0-1.2"	**Parachute materials**	Kevlar/Nylon

APPENDIX I List of Space Vehicles and Their Missions Unmanned Planetary Probes

For a complete list of deep space exploration go to www.nasa.gov –> Downloads –> History E-books –> Beyond Earth: A Chronicle of Deep Space Exploration.

History e-Books | NASA

APPENDIX II Definitions

Entry angle
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. *Y* is negative when *V*, is below the horizontal plane, as in planetary entry.

Entry velocity inertial
The vehicle velocity at reference altitude, *h*, assuming a non-rotating planet.

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

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

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.

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

Peak deceleration
Maximum deceleration force on the vehicle during entry, stated in Earth gravity, g.

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 total apparent or drag area projected along the centerline.

Vehicle entry 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.

Payload mass
The proportion of payload mass (scientific instruments and may include transmitters, batteries etc.) to vehicle mass. For missions with landed payloads and eject-able heatshields/backshells, this is total mass of the vehicle carried within the entry system.

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

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

Peak convective heating
The maximum convective heat flux at the leading edge stagnation point. Depends on trajectory. The stagnation point is a point in the flowfield where the local velocity of the fluid is zero. Location depends on angle of attack and deviation behind the shock. The “peak convective heating” (peak convective heat flux) is often at the entry vehicle’s leading edge stagnation point, but not always.

Peak radiative heating
The maximum radiative heat flux at the leading edge stagnation point. Depends on trajectory. The stagnation point is a point in the flowfield where the local velocity of the fluid is zero. Location depends on angle of attack and deviation behind the shock. The “peak radiative heating” (peak radiative heat flux) is often at the entry vehicle’s leading edge stagnation point, but not always.

Integrated total 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.

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

Peak stag. heating rate
The maximum combined convective and radiative heating rate during the trajectory. Peak convective stagnation point heating seldom occurs at the same time as peak radiative stagnation point heating, therefore, not the simple sum of those values unless one is zero. Peak radiative heating rate (if nonzero) always occurs before peak convective heating rate.

Forebody 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.

Forebody thickness & mass
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.

Ablating / Ejected
Information on whether the forebody TPS material experienced or was designed for ablating. Ejected refers to whether the vehicle was designed to eject the forebody TPS.

TPS integration method
Details on TPS integration method with the supporting substructure. Examples are single piece, direct bonded to substructure; cells filled with ablative compound.

Aftbody 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.

Aftbody thickness & mass
This is “as manufactured” or “as flown” thickness of the material. Descriptions vary by mission, since a common reference point for a thickness specification, such as the stagnation point, doesn’t exist.

Parachute: Type
General parachute design type descriptor for decent or recovery parachutes. Examples include Cross Type, Ringsail, or Disk-Gap-Band (DGB).

Deployment method
Method for releasing parachute system during descent/ entry. An example is mortar fired.

Reference diameter / area
Number to generate reference area, or calculated from reference area of the decelerator, used as a common size reference for interpreting decelerator aerodynamic properties.

Deployment mach
Local Mach number at the time of parachute deployment.

Deployment dynamic pressure
The measured/ calculated dynamic pressure at the forebody at the time of deployment (similar to Mach number).

Parachute materials
Description of parachute materials used for construction, including canopy and suspension lines when possible. Examples include nylon, polyester, and Kevlar.

APPENDIX III Unit Conversion Factors

1 cm = 0.3937 in
1 m = 3.28084 ft
1 m^2 = 10.764 ft^2
1 km/s = 3280.8 ft/s
1 g =. 9.81 m/s^2
1 kg = 2.20462 lb
1 kg/m^2 = 0.2048 lb/ft^2

1 kg/m^3 = 0.06243 lb/ft^3
1 Joule = 0.9478x10^{-3} BTU
1 Watt = 1 J/s = 0.9478x10^{-3} BTU/s
1 J/cm^2 = 0.88055 BTU/ft^2
1 W/cm^2 = 0.88055 $BTU/s*ft^2$
1 atm = 1.01325x105 Pa

APPENDIX IV References

Mission: FIRE II
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2. Cornette, E.S.: Forebody Temperatures and Calorimeter Heating Rates Measured during Project Fire II Re-entry at 11.35 km/s. NASA-TM-X-1305, Nov 1996.
3. Slocumb, T.H.: Project Fire Flight II Afterbody Temperatures and Pressures at 11.35 km/s. NASA-TM-X-1319, Dec 1966.
4. Wright, M.; Loomis, M.; and Papadopoulos, P.: Aerothermal Analysis of the Project Fire II Afterbody Flow. AIAA-2011-3065, 35th Thermophysics Conference, Anaheim Ca, Jun 2011

Collected by: Trajectory Data Verified by: Traj Ver 17.06, Gary A Allen, Jr., 22 Feb 2019

Mission: Apollo AS-201
1. Lee, D.B.; Bertin, J.J.; and Goodrich, W.D.: Heat Transfer and Pressure Measurements Obtained During Apollo Orbital Entries. NASA-TN-D-6028, Oct 1970.
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4. North American Aviation Inc. Space and Information Systems Division, Aerodynamic Data Manuel for Project Apollo, NAS 9-150, Accession No. 07499-65, Feb 1966.
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ARTEMIS I

References will be supplied in a future release.