Planetary Mission Entry Vehicles

Quick Reference Guide

Version 3.0

This is Version 3.0 of the planetary mission entry vehicle document. Three new missions, Re-entry F, Hayabusa, and ARD have been added to the previously published edition (Version 2.1). In addition, the Huygens mission has been significantly updated and some Apollo data corrected.

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.

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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 kg	=	2.20462 lb
1 kg/m^2	=	0.2048 lb/ft^2
1 kg/m^3	=	0.06243 lb/ft^3
1 Joule	=	0.9478×10^{-3} BTU
1 Watt = 1 J/s	=	0.9478×10^{-3} BTU/s
1 J/cm^2	=	0.88055 BTU/ft^2
1 W/cm^2	=	0.88055 $BTU/ft^2.s$
1 atm	=	1.01325×10^5 Pa

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_d) and projected reference area (A) to mass (m), giving m/C_dA.

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.

TABLE OF CONTENTS

APPENDIX II: DEFINITIONS

Entry angle, γ
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. γ 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.

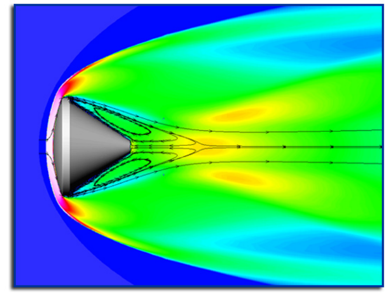
Base area
The base area projected along the centerline.

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.

Date	Spacecraft	Target	Remarks
04/08/64	Gemini 1		Orbital test
01/19/65	Gemini 2		Orbital test
03/23/65	Gemini 3		Earth orbit
06/03/65	Gemini 4		Earth orbit
08/21/65	Gemini 5		Earth orbit
12/15/65	Gemini 6		Gemini 7 rendezvous
12/04/65	Gemini 7		Gemini 6 rendezvous
03/16/66	Gemini 8		Agena docking
06/03/66	Gemini 9		ADTA rendezvous
07/18/66	Gemini 10		Agena docking
09/12/66	Gemini 11		Agena docking
11/11/66	Gemini 12		Agena docking
05/22/65	Fire II		Apollo re-entry test
02/26/66	Apollo 1		Suborbital test
07/05/66	Apollo 2		Suborbital test
08/25/66	Apollo 3		Suborbital test
11/09/67	Apollo 4		Saturn V test
01/22/68	Apollo 5		Orbital test
04/04/68	Apollo 6		Orbital test
10/11/68	Apollo 7		Earth orbit
12/21/68	Apollo 8	Moon	Lunar orbit
03/03/69	Apollo 9		Earth orbital LM test
05/18/69	Apollo 10	Moon	Lunar orbital LM test
07/16/69	Apollo 11	Moon	Lunar landing
11/14/69	Apollo 12	Moon	Lunar landing
04/11/70	Apollo 13	Moon	Lunar landing abort
01/31/71	Apollo 14	Moon	Lunar landing
07/26/71	Apollo 15	Moon	Lunar landing
04/16/72	Apollo 16	Moon	Lunar landing
02/07/72	Apollo 17	Moon	Lunar landing



MISSION: **FIRE II**
PLANET: **EARTH**

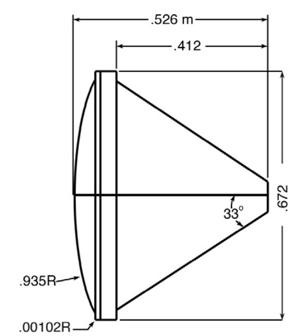
LAUNCH: *May 22, 1965*
ENTRY: *May 22, 1965*

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

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	−14.7°	*Shape*	66° sphere-cone	*Trim L/D (specify trim α)*	0 at 0°	*Material designation*	Beryllium (fore) Phenolic asbestos (aft)
Inertial entry velocity		*Nose radius (3 parts)*	.935 m .805 m .702 m	*Ballistic coeff.*	F(t)	*Thickness*	.3 cm (fore)
Relative entry velocity	11.35 km/s	*Base area*	.354 m^2 .312 m^2 .272 m^2	*Stagnation heating rate*	1140 W/cm^2	*Ablating? Ejected?*	Fore: 3 ejected. Aft: ablating
Velocity at peak heat	10.0 km/s	*Vehicle mass*	86.5 kg	*Integrated heat load*		*Resin mat. Matrix mat.*	
Control method	Ballistic	*TPS mass fraction, inc. insul.*		*Radiative heat flux*	~350 W/cm^2 (.2-.4 μ) implying ~650 total	*Resin dens. Matrix dens.*	
Center of Gravity, X_{CG}/D		*Payload mass*		*PH stag. pressure*	1.046 atm	*Total material density*	

INSTRUMENTATION:
- Three forebody calorimeters, 11 forebody thermocouples, 12 offset radiometer thermocouples and one static pressure transformer on the afterbody

NOTES:
- This aerothermal 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.



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Data Collected by: M. J. Wright

MISSION: **APOLLO AS-201**
PLANET: **EARTH**

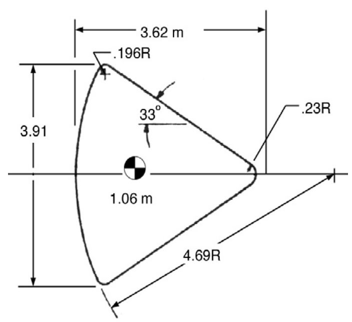
LAUNCH: FEB 26, 1966
ENTRY: FEB 26, 1966

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

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	-8.58° inertial, -9.03° relative	*Shape*	Capsule: 33° cone	*Trim L/D (specify trim α)*	-19.7° < α < 21.3°	*Material designation*	Avco 5026-39 HC
Inertial entry velocity		*Nose radius*	4.69 m, 3 m effective	*Ballistic coeff.*		*Thickness*	See note
Relative entry velocity	7.67 km/s	*Base area*	12.02 m^2	*Stagnation heating rate*	186 W/cm^2 at peak	*Ablating? Ejected?*	No
Velocity at peak heat	5.73 km/s	*Vehicle mass*		*Integrated heat load*	7,600 J/cm^2	*Resin mat. Matrix mat.*	Epoxy-novolac Quartz fiber +phenolic microballoon
Control method	No control: Rolled	*TPS mass fraction, inc. insul.*	13.7%	*Radiative heat flux*	0.00	*Resin dens. Matrix density*	244.6 kg/m^3 300 kg/m^3
Center of Gravity, X_{CG}/D	.27	*Payload mass*	None	*PH stag. pressure*	0.85 atm	*Total material density*	Ablator: 544.6 kg/m^3

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



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UNMANNED PLANETARY PROBES
CONTINUED

DATE	SPACECRAFT	TARGET	REMARKS
	Germany		
12/10/74	Helios 1	Sun	Solar orbit
01/15/76	Helios 2	Sun	Solar orbit
	Japan		
01/18/85	Sakigake	Comet	Halley flyby (3/1/86 - 4.3 mill. mi.)
08/19/85	Suisei	Comet	Halley flyby (3/8/86 - 93,600 mi.)
02/04/94	Orex		Technology demonstrator
09/25/90	Muses A	Moon	Lunar orbit (1992)
07/04/98	Nozomi	Mars	Failed to reach Mars orbit (12/2003)
05/09/03	Hayabusa	Asteroid	To collect samples from Itokawa
	Europe		
07/20/85	Giotti	Comet	Halley flyby (3/14/86 - 400 mi.)
	————>	Comet	Grigg-Skjellerup flyby (7/10/92)
10/09/90	Ulysses	Jupiter	Jupiter flyby (1992)
	————>	Sun	Solar polar orbit (1994)
09/09/97	Mirka		Technology demonstrator
10/13/97	Huygens	Saturn	Titan probe (Jan 2005)
	————>	Titan	Carried by U.S.'s Cassini orbiter
06/02/03	Mars Express	Mars	Carried Beagle 2

MANNED MISSIONS
United States

Mercury Program:

12/19/60	MR-1	Suborbital test
01/31/61	MR-2	Chimp "Ham"
02/21/61	MA-2	Orbital test
05/03/61	MR-3 (Freedom 7)	Suborbital flight
07/21/61	MR-4 (Liberty Bell 7)	Suborbital flight
09/13/61	MA-4	Orbital test
11/29/61	MA-5	Chimp "Enos"
02/20/62	MA-6 (Friendship 7)	Earth orbit
05/24/62	MA-7 (Aurora 7)	Earth orbit
10/03/62	MA-8 (Sigma 7	Earth orbit

Unmanned Planetary Probes
Soviet Union/Russia continued

Date	Spacecraft	Target	Remarks
02/12/61	Venera 1	Venus	Venus flyby (communications failure)
11/12/65	Venera 2	Venus	Venus flyby (communications failure)
11/16/65	Venera 3	Venus	Venus impact (3/1/66 - comm. failure)
06/12/67	Venera 4	Venus	Venus atmospheric entry (10/18/67)
01/05/69	Venera 5	Venus	Venus atmospheric entry (5/16/69)
01/10/69	Venera 6	Venus	Venus atmospheric entry (5/17/69)
08/17/70	Venera 7	Venus	Venus landing (12/5/70)
03/27/72	Venera 8	Venus	Venus landing (7/22/72)
06/08/75	Venera 9	Venus	Venus orbit & landing (10/22/75)
06/14/75	Venera 10	Venus	Venus orbit & landing (10/25/75)
09/09/78	Venera 11	Venus	Venus flyb≠y & landing (12/25/78)
09/14/78	Venera 12	Venus	Venus flyby & landing (12/21/78)
10/20/81	Venera 13	Venus	Venus flyby & landing (3/1/82)
11/04/81	Venera 14	Venus	Venus flyby & landing (3/5/82)
06/02/83	Venera 15	Venus	Venus orbit radar mapper (10/10/83)
06/07/83	Venera 16	Venus	Venus orbit radar mapper (10/14/83)
11/01/62	Mars 1	Mars	Mars flyby (communications failure)
05/19/71	Mars 2	Mars	Mars orbiter/lander crashed (11/26/71)
05/28/71	Mars 3	Mars	Mars orbiter/lander crashed (12/3/71)
07/21/73	Mars 4	Mars	Mars orbiter missed (2/10/74)
07/25/73	Mars 5	Mars	Mars orbit (2/12/74)
08/05/73	Mars 6	Mars	Crashed on Mars (3/12/74)
08/09/73	Mars 7	Mars	Mars lander missed (3/9/74)
04/02/64	Zond 1	Venus	Venus flyby (communications failure)
11/30/64	Zond 2	Mars	Mars flyby (communications failure)
07/18/65	Zond 3	Moon	Lunar flyby (pre-manned test)
03/02/68	Zond 4	Moon	Circumlunar failure (pre-manned test)
09/15/68	Zond 5	Moon	Circumlunar (pre-manned test)
11/10/68	Zond 6	Moon	Circumlunar (pre-manned test)
08/08/69	Zond 7	Moon	Circumlunar (pre-manned test)
10/20/70	Zond 8	Moon	Circumlunar (pre-manned test)
12/15/84	Vega 1	Venus	Venus flyby & landing (6/11/85)
	———>	Comet	Halley flyby (3/6/86 - 5,500 mi.)
12/21/84	Vega 2	Venus	Venus flyby & landing (6/14/85)
	———>	Comet	Halley flyby (3/9/86 - 5,000 mi.)
07/07/88	Phobos 1	Mars	Phobos/Mars orbit (comm. failure)
07/12/88	Phobos 2	Mars	Phobos/Mars orbit (comm. failure)
11/16/96	Mars 96	Mars	2 Mars landers (launch failure)

MISSION: **APOLLO AS-202**
PLANET: **EARTH**

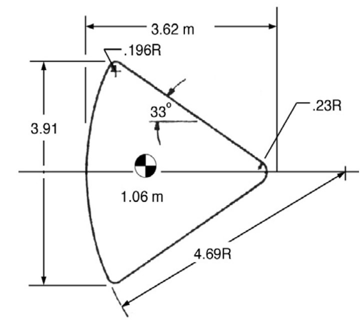
Launch: Aug 25, 1966
Entry: Aug 25, 1966

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

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	-3.53° relative	*Shape*	Capsule: 33° cone	*Trim L/D (specify trim α)*	0.28° < L/D < 0.33° α=21° ±3	*Material designation*	Avco 5026-39 HC/G
Inertial entry velocity		*Nose radius*	4.69 m, 3 m effective	*Ballistic coeff.*		*Thickness*	See note
Relative entry velocity	8.29 km/s	*Base area*	12.02 m^2	*Stagnation heating rate*	107 W/cm^2 at peak	*Ablating? Ejected?*	No
Velocity at peak heat	7.77 km/s	*Vehicle mass*		*Integrated heat load*	24,000 J/ cm^2	*Resin mat. Matrix mat.*	Epoxy-novolac Quartz fiber +phenolic microballoon
Control method	Roll modulation	*TPS mass fraction, inc. insul.*	13.7%	*Radiative heat flux*	0.00	*Resin dens. Matrix density*	244.6 kg/m^3 300 kg/m^3
Center of Gravity, X_{CG}/D	.27	*Payload mass*	None	*PH stag. pressure*	0.11 atm	*Total material density*	Ablator: 544.6 kg/m^3

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



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Data Collected by: C. Park

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

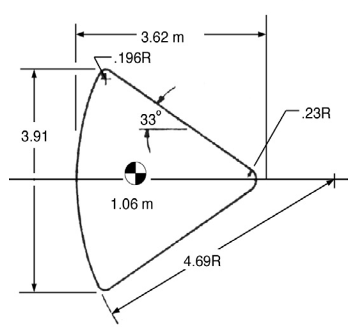
LAUNCH: Nov 9, 1967
ENTRY: Nov 9, 1967

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

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	-6.92° inertial, -7.13° relative	*Shape*	Capsule: 33° cone	*Trim L/D (specify trim α)*	0.37° < L/D < 0.44 24 < α < 28	*Material designation*	Avco 5026-39 HC/G
Inertial entry velocity	11.14 km/s	*Nose radius*	4.69 m, 3 m effective	*Ballistic coeff.*	395.8 kg/m^2	*Thickness*	See note
Relative entry velocity	10.73 km/s	*Base area*	12.02 m^2	*Stagnation heating rate*	490 W/cm^2 at peak	*Ablating? Ejected?*	No
Velocity at peak heat	10.25 km/s	*Vehicle mass*	5424.9 kg	*Integrated heat load*	43,000 J/cm^2	*Resin mat. Matrix mat.*	Epoxy-novolac Quartz fiber +phenolic microballoon
Control method	Roll modulation	*TPS mass fraction, inc. insul.*	13.7%	*Radiative heat flux*	115-264 W/cm^2	*Resin dens. Matrix density*	244.6 kg/m^3 300 kg/m^3
Center of Gravity, X_{CG}/D	.27	*Payload mass*	None	*PH stag. pressure*	0.35 atm	*Total material density*	Ablator: 544.6 kg/m^3

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



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United States CONTINUED

DATE	SPACECRAFT	TARGET	REMARKS
10/24/98	Deep Space 1	Asteroid Braille	Flyby (7/29/99 - 15 mi.)
	———————>	Comet Borrelly	Fyby (9/22/2001 - 1,340 mi.)
12/11/98	Mars Climate Orbiter	Mars	Mars orbit
	———————>		(Presumed destroyed 9/23/99)
01/03/99	Mars Polar Lander	Mars	Mars South Polar lander
	———————>		Carried Deep Space 2 probes
	———————>		(Presumed destroyed 12/3/99)
01/03/99	Deep Space 2	Mars	2 Mars surface penetrators
	———————>		(Presumed destroyed 12/3/99)
02/07/99	Stardust	Comet Wild 2	Sample return (1/15/06)
04/07/01	Mars Odyssey	Mars	Mars orbit
08/08/01	Genesis	Sun	Solar wind sample return (9/8/04)
06/10/03	MER Spirit	Mars	Landed 01/03/04
07/07/03	MER Opportunity	Mars	Landed 01/24/04

Soviet Union/Russia

DATE	SPACECRAFT	TARGET	REMARKS
01/02/59	Luna 1	Moon	Missed the Moon
09/12/59	Luna 2	Moon	Lunar impact
10/04/59	Luna 3	Moon	Lunar flyby/farside photos
04/02/63	Luna 4	Moon	Lunar flyby
05/09/65	Luna 5	Moon	Crashed on the Moon
06/08/65	Luna 6	Moon	Missed the Moon
10/04/65	Luna 7	Moon	Crashed on the Moon
12/03/65	Luna 8	Moon	Crashed on the Moon
01/31/66	Luna 9	Moon	Lunar landing
03/31/66	Luna 10	Moon	Lunar orbit
08/24/66	Luna 11	Moon	Lunar orbit
10/22/66	Luna 12	Moon	Lunar orbit
12/21/66	Luna 13	Moon	Lunar landing
04/07/68	Luna 14	Moon	Lunar orbit
07/14/69	Luna 15	Moon	Crashed on the Moon
09/12/70	Luna 16	Moon	Lunar soil return
11/10/70	Luna 17	Moon	Lunokhod 1 lunar rover
09/02/71	Luna 18	Moon	Crashed on the Moon
09/28/71	Luna 19	Moon	Lunar orbit
02/14/72	Luna 20	Moon	Lunar soil return
01/08/73	Luna 21	Moon	Lunkhod 2 lunar rover
05/29/74	Luna 22	Moon	Lunar orbit
10/28/74	Luna 23	Moon	Lunar landing
08/08/76	Luna 24	Moon	Lunar soil return

Unmanned Planetary Probes

United States continued

Date	Spacecraft	Target	Remarks
08/20/75	Viking 1	Mars	Mars orbit & landing (7/20/76)
09/09/75	Viking 2	Mars	Mars orbit & landing (9/3/76)
08/12/77	ICE (ISEE-3)	Sun	Solar orbit
	————>	Comet	Giacobini-Zinner flyby (9/11/85)
	————>	Comet	Halley flyby (3/25/86)
09/03/77	Voyager 1	Jupiter	Jupiter flyby (3/5/79 - 174,000 mi.)
	————>	Saturn	Saturn flyby (11/12/80 - 77,000 mi.)
08/20/77	Voyager 2	Jupiter	Jupiter flyby (7/9/79 - 400,000 mi.)
	————>	Saturn	Saturn flyby (8/25/81 - 63,000 mi.)
	————>	Uranus	Uranus flyby (1/24/86 - 44,000 mi.)
	————>	Neptune	Neptune flyby (8/25/89 - 15,500 mi.)
05/20/78	Pioneer Venus 1	Venus	Venus orbit radar mapper (12/4/78)
08/08/78	Pioneer Venus 2	Venus	Venus atmospheric probes (12/9/78)
05/04/89	Magellan	Venus	Venus orbit radar mapper (8/10/90)
10/18/89	Galileo	Venus	Venus flyby (2/10/90 - 10,000 mi.)
	————>	Asteroid Gaspa	Flyby (10/29/91 - 1,000 mi.)
	————>	Asteroid Ida	Flyby (8/28/93 - 2,400 mi.)
	————>	Jupiter	Jupiter orbit/probe (12/7/95)
09/25/92	Mars Observer	Mars	Mars orbit (communications failure)
01/25/94	Clementine 1	Moon	Lunar orbit
02/17/96	Shoemaker NEAR	Asteroid Mathilde	Flyby (6/27/97)
	————>	Asteroid Eros	Flyby (12/23/98)
	————>	Asteroid Eros	Orbit (10/26/00)
	————>	Asteroid Eros	Touchdown (2/12/01)
11/07/96	Mars Global Surveyor	Mars	Mars orbit (9/11/97)
12/04/96	Mars Pathfinder	Mars	Sojourner Mars rover (7/4/97)
10/13/97	Cassini	Venus	Venus flyby (4/98)
	————>	Venus	Venus flyby (6/24/99 - 323 mi.)
	————>	Earth	Earth flyby (8/17/99 - 727 mi.)
	————>	Jupiter	Jupiter flyby (12/30/00)
	————>	Saturn	Saturn orbit (6/3/04)
	————>	Titan	Carried ESA's Huygens probe
	————>		Touchdown (1/14/05)
01/06/98	Lunar Prospector	Moon	Lunar orbital mapper

Mission: **APOLLO 6**
Planet: **EARTH**

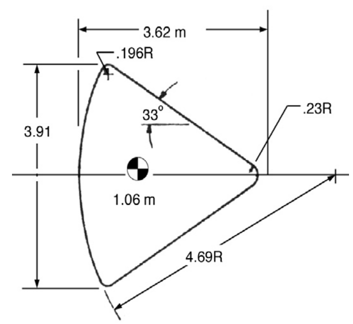
Launch: Apr 4, 1968
Entry: Apr 4, 1968

Mission Description:
Final qualification test for launch vehicle and command module for manned mission

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	-5.9° inertial	*Shape*	Capsule: 33° cone	*Trim L/D (specify trim α)*	0.35° < L/D < 0.4 24° < α < 28°	*Material designation*	Avco 5026-39 HC/G
Inertial entry velocity	10.00 km/s	*Nose radius*	4.69 m, 3 m effective	*Ballistic coeff.*	395.8 kg/m^2	*Thickness*	See note
Relative entry velocity	9.60 km/s	*Base area*	12.02 m^2	*Stagnation heating rate*	240 W/cm^2 at peak	*Ablating? Ejected?*	No
Velocity at peak heat	8.32 km/s	*Vehicle mass*	5424.9 kg	*Integrated heat load*	32,000 J/ cm^2	*Resin mat. Matrix mat.*	Epoxy-novolac Quartz fiber +phenolic microballoon
Control method	Roll modulation	*TPS mass fraction, inc. insul.*	13.7%	*Radiative heat flux*	43 W/cm^2	*Resin dens. Matrix density*	244.6 kg/m^3 300 kg/m^3
Center of Gravity, X_{CG}/D	.27	*Payload mass*	None	*PH stag. pressure*	0.354 atm	*Total material density*	Ablator: 544.6 kg/m^3

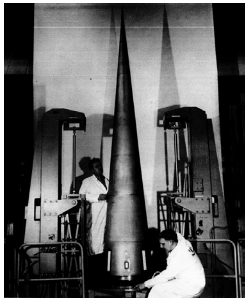
Instrumentation:

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
- Manufacturer: AVCO Corp



References:
1. Hillje, E.R.; and Savage, R.: Status of Aerodynamic Characteristics of the Apollo Entry Configuration. AIAA-1968-1143, Entry Vehicle Systems and Technology Meeting, Williamsburg VA, Dec 1968.
2. Lee, D.B.; and Goodrich, W.D.: The Aerothermodynamic Environment of the Apollo Command Module During Superorbital Entry. NASA-TN-D-6792, Apr 1972.
3. Strouhal, G.; Curry, M.; and Janney, J.M.: Thermal Protection System Performance of the Apollo Command Module. AIAA/ASME 7th Structures and Materials Conference, Cocoa Beach FL, Apr 1966.
4. Bartlett, E.P.; Nicolet, W.E.; Abbett, M.J.; and Moyer, C.B.: Improved Heat-Shield Design Procedures for Manned Entry Systems: Part 2. Application to Apollo: Final Report. NASA-CR-108689, Jun 1970.

Data Collected by: C. Park



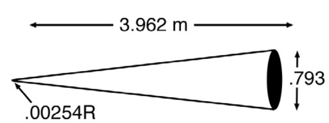
MISSION: **REENTRY F**
PLANET: **EARTH**

LAUNCH: Apr 27, 1968
ENTRY:

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

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	-20.78°	*Shape*	5° half cone, 3.962 m long	*Trim L/D (specify trim α)*	0° ballistic	*Material designation*	Nosetip: ATJ graphite Body: berryllium
Inertial entry velocity	6.28 km/s	*Nose radius*	.254 cm	*Ballistic coeff.*	~50,000 kg/m^2	*Thickness*	Be: 1.524 cm
Relative entry velocity	5.96 km/s	*Base area*	0.3772 m^2	*Stagnation heating rate*	32 W/cm^2	*Ablating? Ejected?*	Nosetip: Yes No
Velocity at peak heat	5.47 km/s	*Vehicle mass*	272 kg	*Integrated heat load*		*Resin mat. Matrix mat.*	
Control method	None	*TPS mass fraction, inc. insul.*		*Radiative heat flux*	~0 W/cm^2	*Resin dens. Matrix density*	
Center of Gravity, X_{cg}/D		*Payload mass*		*PH stag. pressure*	250 atm See note	*Total material density*	

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 beryllum heat shield melted about 40 seconds after entry.

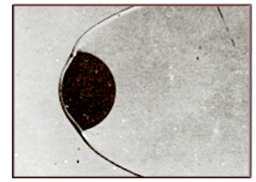
REFERENCES:
1. Wright, R.L.; and Zoby, E.V.: Flight Measurements of Boundary-Layer Transition on a 5 Degree Half-Angle Cone at a Free-Stream Mach Number of 20 (Reentry F). NASA-TM-X-2253, May 1971.

Data Collected by: M.J. Wright and G. Allen

APPENDIX I
LIST OF SPACE VEHICLES AND THEIR MISSIONS

Unmanned Planetary Probes
United States

Date	Spacecraft	Target	Remarks
03/03/59	Pioneer 4	Moon	Lunar flyby
03/11/60	Pioneer 5	Sun	Solar orbit
12/16/65	Pioneer 6	Sun	Solar orbit
08/17/66	Pioneer 7	Sun	Solar orbit
10/18/67	Pioneer 8	Sun	Solar orbit
11/08/68	Pioneer 9	Sun	Solar orbit
03/03/72	Pioneer 10	Jupiter	Jupiter flyby (12/3/73 - 81,000 mi.)
04/05/73	Pioneer 11	Jupiter	Jupiter flyby (12/2/74 - 26,600 mi.)
	———————>	Saturn	Saturn flyby (9/1/79 - 13,000 mi.)
01/26/62	Ranger 3	Moon	Lunar flyby
04/23/62	Ranger 4	Moon	Lunar impact
10/10/62	Ranger 5	Moon	Lunar flyby
01/30/64	Ranger 6	Moon	Lunar impact
07/28/64	Ranger 7	Moon	Lunar impact/photos
02/17/65	Ranger 8	Moon	Lunar impact/photos
03/21/65	Ranger 9	Moon	Lunar impact/photos
08/26/62	Mariner 2	Venus	Venus flyby (12/14/65 - 22,000 mi.)
11/05/64	Mariner 3	Mars	Mars flyby (comm. failure)
11/28/64	Mariner 4	Mars	Mars flyby (7/14/65 - 6,100 mi.)
06/14/67	Mariner 5	Venus	Venus flyby (10/19/67 - 2,500 mi.)
02/25/69	Mariner 6	Mars	Mars flyby (7/31/69 - 2,100 mi.)
03/27/69	Mariner 7	Mars	Mars flyby (8/5/69 - 2,200 mi.)
05/30/71	Mariner 9	Mars	Mars orbit (11/13/71)
11/02/73	Mariner 10	Venus	Venus flyby (2/5/74 -3,600 mi.)
	———————>	Mercury	Mercury flyby (3/29/74 - 460 mi.)
	———————>	Mercury	Mercury flyby (9/21/74 - 30,000 mi.)
	———————>	Mercury	Mercury flyby (3/16/75 - 200 mi.)
06/30/66	Surveyor 1	Moon	Lunar landing
09/20/66	Surveyor 2	Moon	Crashed on the Moon
04/17/67	Surveyor 3	Moon	Lunar landing
07/14/67	Surveyor 4	Moon	Crashed on the Moon
09/08/67	Surveyor 5	Moon	Lunar landing
11/07/67	Surveyor 6	Moon	Lunar landing
01/07/68	Surveyor 7	Moon	Lunar landing
08/10/66	Lunar Orbiter 1	Moon	Lunar orbit
11/06/66	Lunar Orbiter 2	Moon	Lunar orbit
02/04/67	Lunar Orbiter 3	Moon	Lunar orbit
05/04/67	Lunar Orbiter 4	Moon	Lunar orbit
08/01/67	Lunar Orbiter 5	Moon	Lunar orbit



Shadowgraph of PAET Model in Ballistic Range Test

MISSION: **PAET**
PLANET: **EARTH**

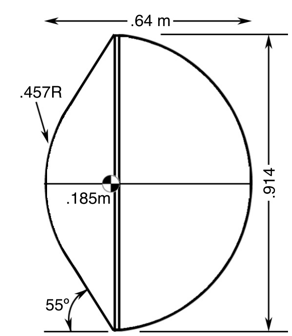
LAUNCH: Jun 2, 1971
ENTRY: Jun 2, 1971

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

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	Relative at 90 km: –40.8°	*Shape*	Blunt-nosed, 55° half-cone angle	*Trim L/D (specify trim α)*	0	*Material designation*	See note
Inertial entry velocity	6.60 km/s	*Nose radius*	0.46 m	*Ballistic coeff.*	69 kg/m^2	*Thickness*	Nose: 1-2.5 cm Conical frustrum: 0.76 cm
Relative entry velocity	6.56 km/s	*Base area*	.66 m^2	*Stagnation heating rate*	(no ablation) Max: 174 W/cm^2	*Ablating? Ejected?*	Yes: frustrum No
Velocity at peak heat	5.6 km/s	*Vehicle mass*	62.1 kg	*Integrated heat load*	Stag. pt. 1450 J/cm^2	*Resin mat. Matrix mat.*	Silicone
Control method	Ballistic	*TPS mass fraction, inc. insul.*	Forebody: 13.7% Afterbody: 3.5%	*Radiative heat flux*	negligible	*Resin dens. Matrix density*	
Center of Gravity, X_{CG}/D	.202	*Payload mass*	14 kg	*PH stag. pressure*	.60 atm	*Total material density*	Beryllium: 1858 kg/m^3 Ablator: 450 kg/m^3

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:
1. Vojvodich, N.S.: PAET Entry Heat Protection Experiment. Journal of Spacecraft and Rockets, Vol 10, No 3, Mar 1973, pp 181-189.
2. Seiff, A.; Reese, D.E.; Sommer, S.C.; Kirk, D.B.; Whiting, E.E; and Niemann, H.B.: PAET, An Entry Probe Experiment in Earth's Atmosphere. ICARUS, Vol 18, Apr 1973, pp 525-563.

Data Collected by: M. Tauber

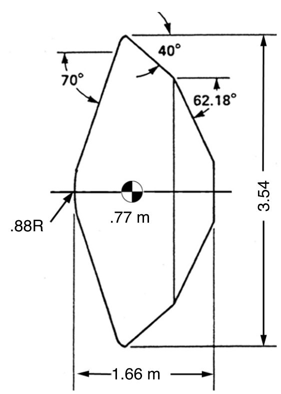
MISSION: **VIKING LANDER 1**
PLANET: **MARS**

LAUNCH: AUG 20, 1975
ENTRY: JUL 20, 1976

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

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	Inertial −16.99°	*Shape*	70° sphere-cone	*Trim L/D (specify trim α)*	α=−11.1°	*Material designation*	SLA561-V
Inertial entry velocity	4.61 km/s	*Nose radius*	0.88 m	*Ballistic coeff.*	At peak heat flux: 63.0 kg/m^2	*Thickness*	Variable: max 1.38 cm
Relative entry velocity	4.42 km/s	*Base area*	9.65 m^2	*Stagnation heating rate*	Peak: 21.02 W/cm^2	*Ablating? Ejected?*	Ablating
Velocity at peak heat	4.02 km/s	*Vehicle mass*	980 kg	*Integrated heat load*	~1100 J/cm^2	*Resin mat. Matrix mat.*	Resin
Control method, e.g. flap deflect.	3-axis RCS	*TPS mass fraction, inc. insul.*	2.8%	*Radiative heat flux*	0	*Resin dens. Matrix dens.*	185 kg/m^3 48 kg/m^3
Center of Gravity, X_{CG}/D	.219 (Ref. 3)	*Payload mass*		*PH stag. Pressure*	.06 atm	*Total material density*	233 kg/m^3

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:

1. Inogoldby, R.N.; Michel, F.C.; Flaherty, T.M.; Doty, M.G.; Preston, B.; Villyard, K.W.; and Steele, R.D.: Entry Data Analysis of Viking Landers 1 and 2: Final Report. Martin-Marietta Co., TN-3770218, NASA-CR-159388, Nov 1976.
2. Kirk, D.B.; Intrieri, P.F.; and Seiff, A.: Aerodynamic Behavior of the Viking Entry Vehicle: Ground Test and Flight Results. Journal of Spacecraft and Rockets, Vol 15, No 4, Jul-Aug 1978.
3. Viking '75 Project, Aerodynamics Data Book. NAS1-9000, Martin-Marietta, Revision E, 1974.
4. Cooley, C.G.: Viking 75 Project: Viking Lander System, Primary Mission Performance Report. NASA-CR-145148, Apr 1977.

Data Collected by: M. Tauber and G. Allen

MISSION: **MARS EXPLORATION ROVERS**
"Spirit" and "Opportunity"
PLANET: **MARS**

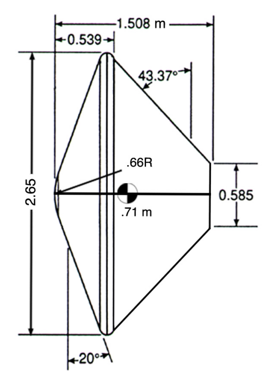
LAUNCH: JUN 10, 2003 & JUL 7, 2003
ENTRY: JAN 3, 2004 & JAN 24, 2004

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

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	-11.5° @ 125 km	*Shape*	70° sphere-cone	*Trim L/D (specify trim α)*	0	*Material designation*	SLA-561V (SLA-561S for backshell)
Inertial entry velocity		*Nose radius*	0.66 m	*Ballistic coeff.*	88 kg/m^2	*Thickness*	1.57 cm
Relative entry velocity	5.55 km/s	*Base area*	5.52 m^2	*Stagnation heating rate*	44 W/cm^2	*Ablating? Ejected?*	Yes
Velocity at peak heat	4.93 km/s	*Vehicle mass*	836 kg	*Integrated heat load*	3687 J/cm^2	*Resin mat. Matrix mat.*	Resin
Control method	Ballistic	*TPS mass fraction, inc. insul.*	3.6% fore body; 2% back shell	*Radiative heat flux*	~0	*Resin dens. Matrix density*	
Center of Gravity, X_{CG}/D	0.30	*Payload mass*		*PH stag. pressure*	0.06 atm	*Total material density*	256 kg/m^3

INSTRUMENTATION:

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.



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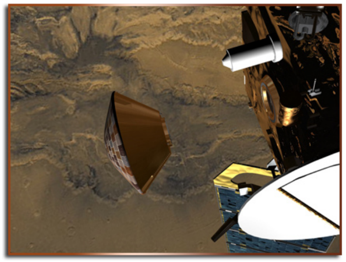
1. Roncoli, R.B.; and Ludwinski, J.M.: Mission Design Overview for the Mars Exploration Rover Mission. AIAA-2002-4823, AIAA/AAAS Astrodynamics Specialist Conference and Exhibit, Monterey CA, Aug 2002.
2. Szalai, C.; Chen Y.; Loomis, M.; and Hui, F.: Mars Exploration Rover TIRS Cover Thermal Protection System Design Verification. AIAA-2003-3767, 36th AIAA Thermophysics Conference, Orlando FL, Jun 2003.

Data Collected by: M. Loomis



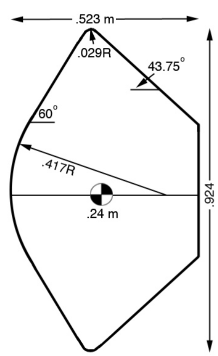
MISSION: **BEAGLE 2**
PLANET: **MARS**

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

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	Inertial: -15.8°	*Shape*	60° sphere-cone	*Trim L/D (specify trim α)*	Ballistic (2° average)	*Material designation*	Norcoat-Liege (EADS)
Inertial entry velocity	5.63 km/s	*Nose radius*	0.417 m	*Ballistic coeff.*	At peak heat flux: 69.9 kg/m^2	*Thickness*	8mm
Relative entry velocity	5.40 km/s	*Base area*	0.67 m^2	*Stagnation heating rate*	72.28 W/cm^2	*Ablating? Ejected?*	Yes Yes
Velocity at peak heat	Relative: 4.70 km/s	*Vehicle mass*	At entry: 68.46 kg	*Integrated heat load*	2449 J/cm^2	*Resin mat. Matrix mat.*	Phenolic Cork
Control method	Ballistic	*TPS mass fraction, inc. insul.*	9.2% fore body; 15.2% back shell	*Radiative heat flux*	0.17 W/cm^2	*Resin dens. Matrix density*	
Center of Gravity, X_{CG}/D	0.26	*Payload mass*	11.4kg (science) (33.2 kg landed)	*PH stag. pressure*	0.18 atm	*Total material density*	460 kg/m^3

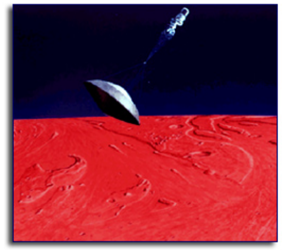
INSTRUMENTATION:
- No TPS instrumentation: axial accelerometers only



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:

1. Burnell, S.; Liever P.; Smith, A.; and Parnaby, G.: Prediction of the Beagle 2 Static Aerodynamic Coefficients. Atmospheric Reentry Vehicles and Systems, Arcachon 2000.
2. Smith, A.; Parnaby, G.; Jones, T.V.; and Buttsworth, D.: Aerothermal Environment of the Beagle 2 Probe. Fourth European Symposium on Aerothermodynamics, Capua, Italy, Oct 2001.
3. Liever, P.A.; Habchi, S.D.; Burnell, S.I.; and Lingard, J.S.: Computational Fluid Dyanamics Prediction of the Beagle 2 Aerodynamic Database. Journal of Spacecraft and Rockets, Vol 40, No 5, Sep-Oct 2003.



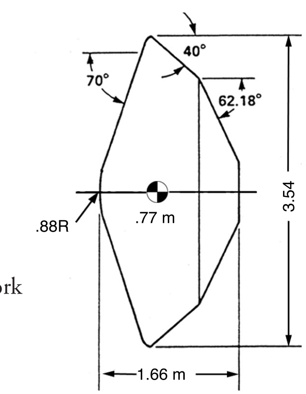
MISSION: **VIKING LANDER 2**
PLANET: **MARS**

LAUNCH: SEP 9, 1975
ENTRY: SEP 3, 1976

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

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	Inertial: (at 138 km) −17.08°	*Shape*	Blunt-nosed 70° half cone	*Trim L/D (specify trim α)*	0.18 at α=−11.3°	*Material designation*	SLA-561V
Inertial entry velocity	4.74 km/s	*Nose radius*	0.88 m	*Ballistic coeff.*	63.6 kg/m^2	*Thickness*	Variable: max 1.38 cm
Relative entry velocity	(at 244 km) 4.48 km/s	*Base area*	9.65 m^2	*Stagnation heating rate*	(max) 21.4 W/cm^2	*Ablating? Ejected?*	Ablator-pyrolyzed Ejected:yes
Velocity at peak heat	4.0 km/s	*Vehicle mass*	981.5 kg	*Integrated heat load (stag pt)*	Approx. 1050 J/cm^2	*Resin mat. Matrix mat.*	See notes
Control method, e.g. flap deflect.	Active-reaction control	*TPS mass fraction, inc. insul.*	2.8%	*Radiative heat flux*	0	*Resin dens. Matrix dens.*	185.0 kg/m^3 48.0 kg/m^3
Center of Gravity, X_{CG}/D	.219	*Payload mass*		*PH stag. Pressure*	0.063 atm	*Total material density*	

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

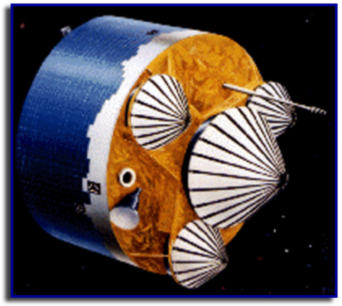
REFERENCES:

1. Inogoldby, R.N.; Michel, F.C.; Flaherty, T.M.; Doty, M.G.; Preston, B.; Villyard, K.W.; and Steele, R.D.: Entry Data Analysis of Viking Landers 1 and 2: Final Report. Martin-Marietta Co., TN-3770218, NASA-CR-159388, Nov 1976.
2. Kirk, D.B.; Intrieri, P.F.; and Seiff, A.: Aerodynamic Behavior of the Viking Entry Vehicle: Ground Test and Flight Results. Journal of Spacecraft and Rockets, Vol 15, No 4, Jul-Aug 1978.
3. Viking '75 Project, Aerodynamics Data Book. NAS1-9000, Martin-Marietta, Revision E, 1974.
4. Cooley, C.G.: Viking 75 Project: Viking Lander System, Primary Mission Performance Report. NASA-CR-145148, Apr 1977.

MISSION: **PIONEER-VENUS**
SMALL "NORTH PROBE"
PLANET: **VENUS**

LAUNCH: AUG 8, 1978
ENTRY: DEC 9, 1978

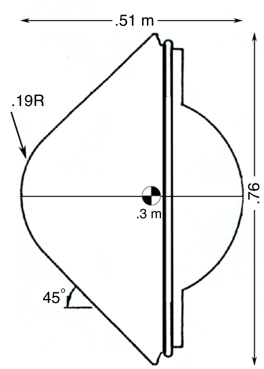
MISSION DESCRIPTION:
A 60° N day entry to map atmosphere, including characterizing wind and turbulence



Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	-68.7° at 200 km	*Shape*	Blunt-nosed, 45° half-cone angle	*Trim L/D (specify trim α)*	0	*Material designation*	Carbon-phenolic
Inertial entry velocity	11.54 km/s	*Nose radius*	0.19 m	*Ballistic coeff.*	190 kg/m^2	*Thickness*	1.2 cm at stagnation point
Relative entry velocity	Same	*Base area*	0.46 m^2	*Stagnation heating rate*	7200 W/cm^2	*Ablating? Ejected?*	Yes No
Velocity at peak heat	10.50 km/s	*Vehicle mass*	91 kg	*Integrated heat load*	At stag. pt. 11,700 J/cm^2	*Resin mat. Matrix mat.*	89.8% Carbon 2.8% Hydrogen 6.9% Oxygen
Control method	Ballistic	*TPS mass fraction, inc. insul.*	12.9%	*Radiative heat flux*	@ max heat 3400 W/cm^2	*Resin dens. Matrix density*	
Center of Gravity, X_{CG}/D	0.40	*Payload mass*	3.60 kg	*PH stag. pressure*	6.40 atm	*Total material density*	1490 kg/m^3

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/R_n=2.2

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



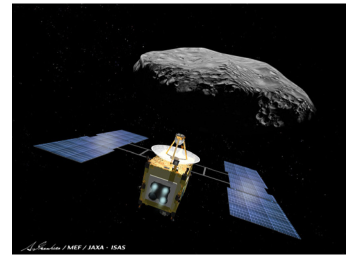
REFERENCES:

1. Nolte, L.J.; and Sommer, S.C.: Probing a Planetary Atmosphere: Pioneer-Venus Spacecraft Description. AIAA-1975-1160, Conference on the Exploration of the Outer Planets, St. Louis MO, Sep 1975.
2. Pioneer-Venus Large and Small Probe Databook, Bendix, NAS2-830Q, Jun 1976.
3. Allen, G.: Trajectory and Heating calculated using TRAJ Code, private communication, Mar 2003.

MISSION: **HAYABUSA**
PLANET: **EARTH RETURN**

LAUNCH: MAY 9, 2003
ENTRY: JUN 2007

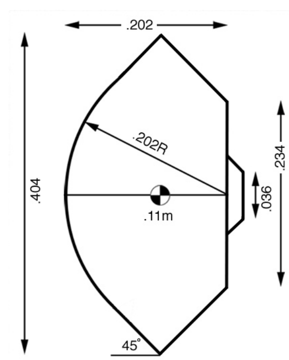
MISSION DESCRIPTION:
To collect samples from asteroid Itokawa (1998SF36) and return to Earth



Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	-13.8°	*Shape*	45° sphere-cone	*Trim L/D (specify trim α)*	0	*Material designation*	Carbon-phenolic
Inertial entry velocity	11.7 km/s	*Nose radius*	.202 m	*Ballistic coeff.*	113.5 kg/m^3	*Thickness*	3.0 cm
Relative entry velocity	11.3 km/s	*Base area*	.128 m^2	*Stagnation heating rate*	1500 W/cm^2	*Ablating? Ejected?*	Yes Yes
Velocity at peak heat	10.2 km/s	*Vehicle mass*	16.27 kg	*Integrated heat load*	32,000 J/cm^2	*Resin mat. Matrix mat.*	
Control method	none	*TPS mass fraction, inc. insul.*	43%	*Radiative heat flux*	300 W/cm^2	*Resin dens. Matrix density*	
Center of Gravity, X_{CG}/D	0.28	*Payload mass*	1.04 kg	*PH stag. pressure*	0.61 atm	*Total material density*	1400 kg/m^3

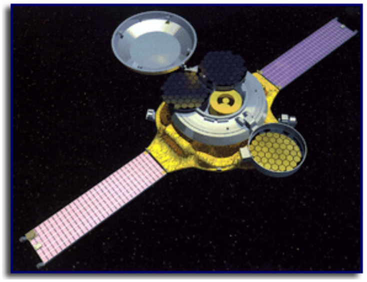
INSTRUMENTATION:
- A one-axis accelerometer for parachute deployment.

NOTES:
- The mission name was changed from MUSES-C



REFERENCES:

1. Ishii, N.; Hiraki, K.; Yamada, T.; Inatani, Y.; and Honda, M.: System Description and Reentry Operation Scenario of MUSES-C Reentry Capsule. Institute of Space and Astronautical Science Report, SP No 17, edited by Y. Inatani, Mar 2003, pp 389-400.



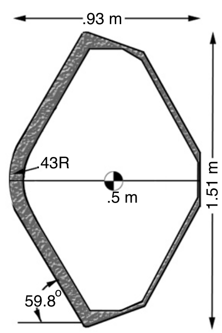
MISSION: **GENESIS**
PLANET: **EARTH RETURN**

LAUNCH: Aug 8, 2001
ENTRY: Sep 8, 2004

MISSION DESCRIPTION:
To collect solar wind particles and return to Earth

Entry angle	-8°	*Shape*	59.81° blunt cone	*Trim L/D (specify trim α)*	0	*Material designation*	Fore: Carbon-carbon Aft: SLA-561V
Inertial entry velocity	11.0 km/s	*Nose radius*	.43 m	*Ballistic coeff.*	80 kg/m^3	*Thickness*	6 cm
Relative entry velocity	10.8 km/s	*Base area*	1.78 m^2	*Stagnation heating rate*	700 W/cm^2	*Ablating? Ejected?*	Partially No
Velocity at peak heat	9.2 km/s	*Vehicle mass*	210 kg	*Integrated heat load*	16,600 J/cm^2	*Resin mat. Matrix mat.*	
Control method	Spin-stabilized aero-ballistic	*TPS mass fraction, inc. insul.*	~18%	*Radiative heat flux*	30 W/cm^2	*Resin dens. Matrix density*	
Center of Gravity, X_{CG}/D	.33	*Payload mass*		*PH stag. pressure*		*Total material density*	

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:

1. Lo, M.W.; Williams, B.G.; Bollman, E.; Han, D.; Hahn, Y.; Bell, J.L.; Hirst, E.A.; Corwin, R.A., Hong, P.E.; and Howell, K.C.: Genesis Mission Design. AIAA-1998-4468, AIAA/AAS Astrodynamics Specialist Conference and Exhibit, Boston MA, Aug 1998.
2. Cheatwood, F. M.; Merski, N. R.; Riley, C.J.; and Mitcheltree, R.A.: Aerothermodynamic Environment Definition for the Genesis Sample Return Capsule. AIAA-2001-2889, 35th AIAA Thermophysics Conference, Anaheim CA, Jun 2001.

Data Collected by: W. Willcockson and R. Bennett

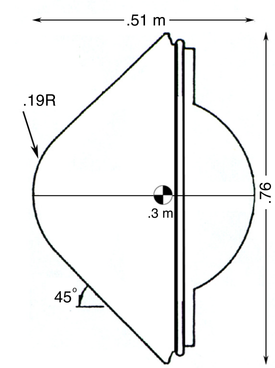
MISSION: **PIONEER-VENUS**
SMALL "NIGHT PROBE"
PLANET: **VENUS**

LAUNCH: Aug 8, 1978
ENTRY: Dec 9, 1978

MISSION DESCRIPTION:
To map the atmosphere, including temperature and pressure, from a night side entry

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	-41.5° at 200 km	*Shape*	Blunt-nosed, 45° half-cone angle	*Trim L/D (specify trim α)*	0	*Material designation*	Carbon-phenolic
Inertial entry velocity	11.54 km/s	*Nose radius*	0.19 m	*Ballistic coeff.*	190 kg/m^2	*Thickness*	1.2 cm at stagnation point
Relative entry velocity	Same	*Base area*	0.46 m^2	*Stagnation heating rate*	5500 W/cm^2	*Ablating? Ejected?*	Yes No
Velocity at peak heat	10.40 km/s	*Vehicle mass*	91 kg	*Integrated heat load*	At stag. pt. 12,500 J/cm^2	*Resin mat. Matrix mat.*	89.8% Carbon 2.8% Hydrogen 6.9% Oxygen
Control method	Ballistic	*TPS mass fraction, inc. insul.*	12.9%	*Radiative heat flux*	2300 W/cm^2	*Resin dens. Matrix density*	
Center of Gravity, X_{CG}/D	0.40	*Payload mass*	3.60 kg	*PH stag. pressure*	6.30 atm	*Total material density*	1490 kg/m^3

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/R_n=2.2



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

REFERENCES:

1. Nolte, L.J.; and Sommer, S.C.: Probing a Planetary Atmosphere: Pioneer-Venus Spacecraft Description. AIAA-1975-1160, Conference on the Exploration of the Outer Planets, St. Louis MO, Sep 1975.
2. Pioneer-Venus Large and Small Probe Databook, Bendix, NAS2-830Q, Jun 1976.
3. Allen, G.: Trajectory and Heating calculated using TRAJ Code, private communication, Mar 2003.

Data Collected by: M. Tauber and G. Allen

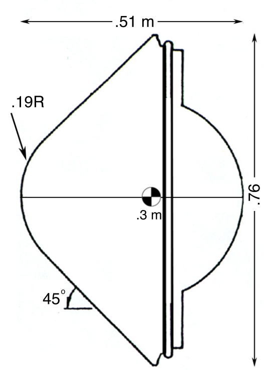
MISSION: **PIONEER-VENUS**
SMALL "DAY PROBE"
PLANET: **VENUS**

LAUNCH: AUG 8, 1978
ENTRY: DEC 9, 1978

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

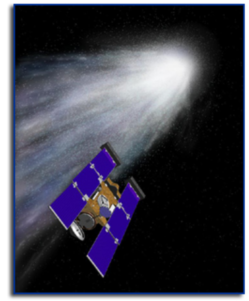
Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	-25.4° at 200 km	*Shape*	Blunt-nosed, 45° half-cone angle	*Trim L/D (specify trim α)*	0	*Material designation*	Carbon-phenolic
Inertial entry velocity	11.54 km/s	*Nose radius*	0.19 m	*Ballistic coeff.*	190 kg/m^2	*Thickness*	1.2 cm at stagnation point
Relative entry velocity	Same	*Base area*	0.46 m^2	*Stagnation heating rate*	3900 W/cm^2	*Ablating? Ejected?*	Yes No
Velocity at peak heat	10.40 km/s	*Vehicle mass*	91 kg	*Integrated heat load*	At stag. pt. 14,000 J/cm^2	*Resin mat. Matrix mat.*	89.8% Carbon 2.8% Hydrogen 6.9% Oxygen
Control method	Ballistic	*TPS mass fraction, inc. insul.*	12.9%	*Radiative heat flux*	1300 W/cm^2	*Resin dens. Matrix density*	
Center of Gravity, X_{CG}/D	0.40	*Payload mass*	3.60 kg	*PH stag. pressure*	4.20 atm	*Total material density*	1490 kg/m^3

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/R_n=2.2



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

REFERENCES:
1. Nolte, L.J.; and Sommer, S.C.: Probing a Planetary Atmosphere: Pioneer-Venus Spacecraft Description. AIAA-1975-1160, Conference on the Exploration of the Outer Planets, St. Louis MO, Sep 1975.
2. Pioneer-Venus Large and Small Probe Databook, Bendix, NAS2-830Q, Jun 1976.
3. Allen, G.: Trajectory and Heating calculated using TRAJ Code, private communication, Mar 2003.



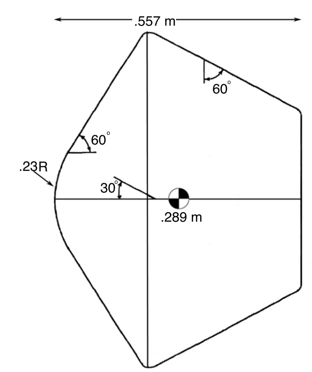
MISSION: **STARDUST**
PLANET: **EARTH RETURN**

LAUNCH: FEB 7, 1999
ENTRY: JAN 15, 2006

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

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	−8.2° ± 0.08° @ 125 km	*Shape*	Blunt-nosed 60° half-angle cone	*Trim L/D (specify trim α)*	0	*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/m^2 60.4 kg/m^2	*Thickness*	5.82 cm
Relative entry velocity	12.6 km/s @ 125 km	*Base area (Ablated)*	0.52 m^2 0.50 m^2	*Stagnation heating rate*	(non-ablating) 1200 W/cm^2	*Ablating? Ejected?*	Yes No
Velocity at peak heat	11.1 km/s	*Vehicle mass*	45.8 kg	*Integrated heat load*	36,000 J/cm^2	*Resin mat. Matrix mat.*	Phenolic Carbon fiber
Control method	Ballistic	*TPS mass fraction, inc. insul.*	22%	*Radiative heat flux*	130 W/cm^2	*Resin dens. Matrix density*	109 kg/m^3 160 kg/m^3
Center of Gravity, X_{CG}/D	.35	*Payload mass*		*PH stag. pressure*	0.275 atm	*Total material density*	250 kg/m^3 approx.

INSTRUMENTATION:



NOTES:
- The rendezvous with Wild 2 occurred on Jan 2, 2004.
- The Stardust capsule made a successful return to Earth on Jan 15, 2006.

REFERENCES:
1. Olynick, D.; Chen, Y.K.; and Tauber, M.E.: Aerothermodynamics of the Stardust Sample Return Capsule. Journal of Spacecraft and Rockets, Vol 36, No 3, May-Jun 1999, pp 442-462.
2. Mitcheltree, R.A.; Wilmoth, R.G.; Cheatwood, F.M.; Brauckmann, G.J.; and Greene, F.A.: Aerodynamics of Stardust Sample Return Capsule. AIAA-1997-2304, 15th Applied Aerodynamics Conference, Atlanta GA, Jun 1997.

MISSION: DEEP SPACE 2
PLANET: MARS

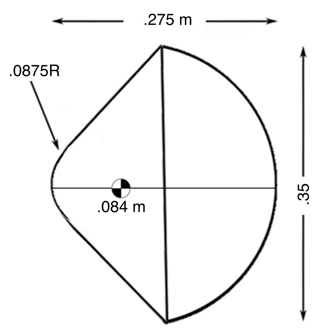
LAUNCH: JAN 3, 1999
ENTRY: DEC 3, 1999

MISSION DESCRIPTION:
To penetrate the Martian surface with two small probes

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	inertial −13.25° at 128 km	*Shape*	45° sphere-cone, spherical aft	*Trim L/D (specify trim α)*	0	*Material designation*	Sirca-SPLIT
Inertial entry velocity		*Nose radius*	.0875 m	*Ballistic coeff.*	36.2 kg/m^2	*Thickness*	~1cm
Relative entry velocity	6.9 km/s	*Base area*	.096 m^2	*Stagnation heating rate*	194 W/cm^2	*Ablating? Ejected?*	Not ejected
Velocity at peak heat	5.94 km/s	*Vehicle mass*	3.67 kg	*Integrated heat load*	8712 J/cm^2	*Resin mat. Matrix mat.*	
Control method	Ballistic	*TPS mass fraction, inc. insul.*		*Radiative heat flux*		*Resin dens. Matrix density*	
Center of Gravity, X_{CG}/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:
1. Mitcheltree, R.A.; DiFulvio, M.; Horvath, T.J.; and Braun, R.D.: Aerothermal Heating Predictions for Mars Microprobe. AIAA-1998-0170, 36th Aerospace Sciences Meeting, Reno NV, Jan 1998.

Data Collected by: M. Murbach and M. Tauber

MISSION: PIONEER-VENUS
LARGE PROBE "SOUNDER"
PLANET: VENUS

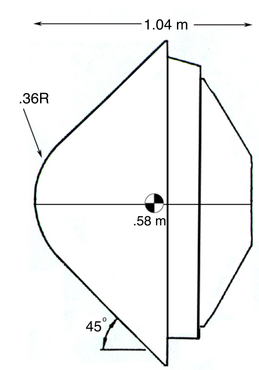
LAUNCH: AUG 8, 1978
ENTRY: DEC 9, 1978

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

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	-32.4° at 200 km	*Shape*	Blunt-nosed, 45° half-cone angle	*Trim L/D (specify trim α)*	0	*Material designation*	Carbon-phenolic
Inertial entry velocity	11.54 km/s	*Nose radius*	0.36 m	*Ballistic coeff.*	188 kg/m^2	*Thickness*	1.60 cm at stagnation point
Relative entry velocity	Same	*Base area*	1.59 m^2	*Stagnation heating rate*	4500 W/cm^2	*Ablating? Ejected?*	Yes Yes
Velocity at peak heat	10.50 km/s	*Vehicle mass*	316.48 kg	*Integrated heat load*	At stag. pt. 12,400 J/cm^2	*Resin mat. Matrix mat.*	89.8% Carbon 2.8% Hydrogen 6.9% Oxygen
Control method	Ballistic	*TPS mass fraction, inc. insul.*	Forebody: 8.83% Aft cover: 1.52%	*Radiative heat flux*	2400 W/cm^2	*Resin dens. Matrix density*	
Center of Gravity, X_{CG}/D	0.40	*Payload mass*	Science instr. 29.15 kg (9.2%)	*PH stag. pressure*	5.30 atm	*Total material density*	1490 kg/m^3

INSTRUMENTATION:
- Thermocouples: one at the 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/R_n=2.2

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



REFERENCES:
1. Nolte, L.J.; and Sommer, S.C.: Probing a Planetary Atmosphere: Pioneer-Venus Spacecraft Description. AIAA-1975-1160, Conference on the Exploration of the Outer Planets, St. Louis MO, Sep 1975.
2. Pioneer-Venus Large and Small Probe Databook, Bendix, NAS2-830Q, Jun 1976.
3. Allen, G.: Trajectory and Heating calculated using TRAJ Code, private communication, Mar 2003.

Data Collected by: M. Tauber and G. Allen

MISSION: **GALILEO**
PLANET: **JUPITER**

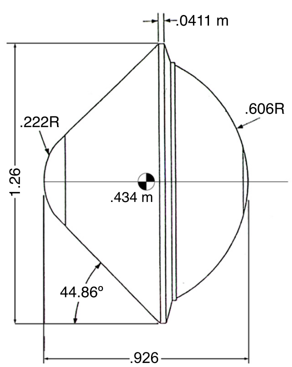
LAUNCH: OCT 18, 1989
ENTRY: DEC 7, 1995

MISSION DESCRIPTION:
To descend into the Jovian atmosphere, collect atmospheric data and relay to the orbiter

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	Inertial: −6.64°, Rel: −8.5°, @ 450 km	*Shape*	Blunt-nosed, 44.86° half-cone angle	*Trim L/D (specify trim α)*	0	*Material designation*	Carbon-phenolic
Inertial entry velocity	59.92 km/s	*Nose radius (initial)*	.222 m	*Ballistic coeff. (at entry)*	256 kg/m^2	*Thickness*	14.6 cm at stagnation
Relative entry velocity	47.37 km/s	*Base area (at entry)*	1.26 m^2	*Stagnation heating rate*	17,000 W/cm^2	*Ablating? Ejected?*	Yes Yes
Velocity at peak heat (relative)	39.0 km/s	*Vehicle mass*	At entry: 335 kg	*Integrated heat load*	200,000 J/cm^2 with ablation	*Resin mat. Matrix mat.*	Phenolic Carbon
Control method	Ballistic	*TPS mass fraction, inc. insul.*	Forebody: 45.4% Afterbody: 5%	*Radiative heat flux (stag point)*	17,000 W/cm^2 (with ablation)	*Resin dens. Matrix density*	
Center of Gravity, X_{CG}/D	.344? see note	*Payload mass*	Science 8.3%	*Peak Heat stag. pressure*	7.3 atm	*Total material density*	1450 kg/m^3

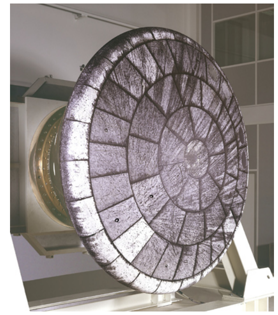
INSTRUMENTATION:
- Forebody TPS: ablation recession gauges
- Afterbody TPS: thermocouples in the nylon phenolic

NOTES:
- Reported CG estimates varied widely.



REFERENCES:
1. Givens, J.; Nolte, L.; and Pochettino, L.: Galileo Atmospheric Entry Probe System: Design, Development and Test. AIAA-1983-0098, 21st Aerosciences Meeting, Jan 1983.
2. Milos, F.; Chen, Y.K.; Squire, T.; and Brewer, R.: Analysis of Galileo Probe Heat Shield Ablation and Temperature Data. AIAA-1997-2480, 32nd Thermophysics Conference, Atlanta GA, Jun 1997.
3. Milos, F.: Galileo Probe Heat Shield Ablation Experiment. AIAA Journal of Spacecraft and Rockets, Vol 34, No 6, Nov-Dec 1997.

Data Collected by: M. Tauber



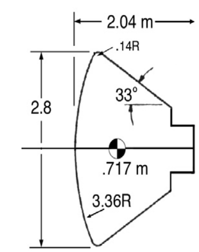
MISSION: **ARD**
"Atmospheric Reentry Demonstrator"
PLANET: **EARTH**

LAUNCH: OCT 21, 1998
ENTRY: OCT 21, 1998

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

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	-2.6°	*Shape*	Apollo-like capsule, 33° cone	*Trim L/D (specify trim α)*	-21.2°	*Material designation*	Fore: Aleastr-asil tiles. Aft: Norcoat 622-50FI (See note)
Inertial entry velocity	8.01 km/s	*Nose radius*	3.36 m	*Ballistic coeff.*	403 kg/m^2	*Thickness*	Norcoat: 19mm Aleastrasil 40-65 mm
Relative entry velocity	7.54 km/s	*Base area*	6.15 m^2	*Stagnation heating rate*	Max recorded temp. was 950-1050°C	*Ablating? Ejected?*	Yes, but low
Velocity at peak heat		*Vehicle mass*	2715 kg (inc. 1017 kg front heat shield)	*Integrated heat load*	Designed for 17,700 J/cm^2	*Resin mat. Matrix mat.*	
Control method	RCS: 7 thrusters	*TPS mass fraction, inc. insul.*	23% (626 kg TPS)	*Radiative heat flux*	Max design 110 W/cm^2	*Resin dens. Matrix density*	
Center of Gravity, X_{CG}/D	.256	*Payload mass*	No payload	*PH stag. pressure*	.22 atm	*Total material density*	Norcoat: 0.47 Aleastrasil: 1.65

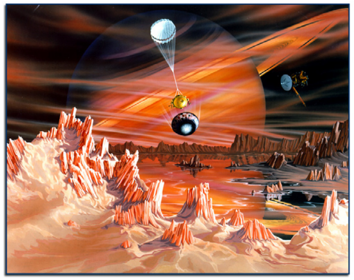
INSTRUMENTATION:
- The capsule afterbody was instrumented with 7 surface pressure sensors, 2 thermal plugs with 2 thermocouples each on the back cover, and 4 surface-mounted copper calorimeters on the cylindrical section.
- The front cone contained 18 pressure sensors, 14 thermal plugs with 3 or 5 TC 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:
1. The Atmospheric Reentry Demonstrator. ESA publication BR-138, Oct 1998.
2. Johnston, I.A.; Weiland, M.; Schramm, J.M.; Hannemann, K.; and Longo, J.: Aerothermodynamics of the ARD: Postflight Numerics and Shock-Tunnel Experiments. AIAA-2002-0407, 40th Aerospace Sciences Meeting, Reno NV, Jan 2002.
3. Tran, P.; and Soler, J.: Atmospheric Reentry Demonstrator Post Flight Analysis: Aerothermal Environment. Proceedings of the 2nd Intl Symposium on Atmospheric Reentry Vehicles, Arcachon, France, Mar 2001.

Data Collected by: F. Casaux and M. J. Wright

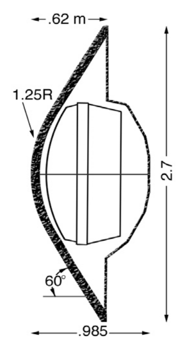


MISSION: **HUYGENS**
PLANET: **TITAN**
A moon of Saturn

LAUNCH: OCT 15, 1997
ENTRY: JAN 14, 2005

MISSION DESCRIPTION:
To explore the atmosphere of Titan

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	-65.4° relative -65.5° inertial	*Shape*	60° sphere-cone	*Trim L/D (specify trim α)*	0	*Material designation*	Fore: AQ60 Aft: Prosial
Inertial entry velocity	6.0 km/s at 1270 km	*Nose radius*	1.25 m	*Ballistic coeff.*	34.5-37.5 kg/m^2	*Thickness*	17.4 mm at stag; 18.2 mm on flank
Relative entry velocity	6.0 km/s	*Base area*	5.73 m^2	*Stagnation heating rate*	50 W/cm^2	*Ablating? Ejected?*	Yes Yes
Velocity at peak heat	~5.1 km/s	*Vehicle mass*	318 kg	*Integrated heat load*	~40 kJ/cm^2	*Resin mat. Matrix mat.*	Phenolic Silica fiber
Control method	Ballistic	*TPS mass fraction, inc. insul.*	Forebody: 25% Aft: 5.1%	*Radiative heat flux*	15-45 W/cm^2	*Resin dens. Matrix density*	
Center of Gravity, X_{CG}/D		*Payload mass*	44 kg	*PH stag. pressure*	.1 atm	*Total material density*	280 kg/m^3



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

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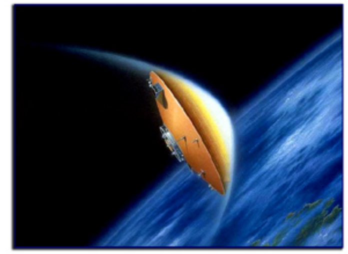
1. Jones, J.C.; and Giovagnoli, F.: Huygens: Science, Payload and Mission. A. Wilson, editor, ESA-SP-1177, Aug 1997.
2. Baillion, M.; and Pallegoix, J.F.: Huygens Probe Aerothermodynamics. Aerospatiale Espace and Defense copyrighted document, AIAA-1997-2476, 32nd Thermophysics Conference, Atlanta GA, Jun 1997.
3. Bouilly, J.M.; and Guerrier, D.: Entry Testing of AQ60 for Huygens. Presented at the First ESA/ESTEC Workshop on Thermal Protection Systems, Noordwidjk, The Netherlands, May 1993.
4. Wright, M.J.; Olejniczak, J.; Walpot, L.; Raynaud, E.; Magin, T.; Callaut, L.; and Hollis, B.: A Code Calibration Study for Huygens Entry Aeroheating. AIAA-2006-0382, 44th Aerospace Sciences Meeting, Reno NV, Jan 2006.

Data Collected by: J. Olejniczak

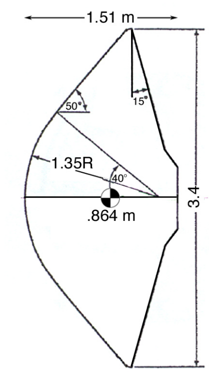


MISSION: **OREX**
PLANET: **EARTH**

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

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	Relative −3.17°	*Shape*	50° sphere-cone	*Trim L/D (specify trim α)*	0	*Material designation*	Si Coated C-C for nose Ceramic tile
Inertial entry velocity	7.8 km/s	*Nose radius*	1.35 m	*Ballistic coeff.*	56 kg/m^2	*Thickness*	4 cm
Relative entry velocity	7.43 km/s	*Base area*	9.08 m^2	*Stagnation heating rate*	51 W/cm^2	*Ablating? Ejected?*	No No
Velocity at peak heat	6.4 km/s	*Vehicle mass*	761 kg at entry	*Integrated heat load*		*Resin mat. Matrix mat.*	
Control method	RCS	*TPS mass fraction, inc. insul.*		*Radiative heat flux*		*Resin dens. Matrix density*	
Center of Gravity X_{CG}/D	.254	*Payload mass*		*PH stag. Pressure*	.078 atm	*Total material density*	1800 kg/m^3



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:

1. Yamamoto, Y.; and Yoshioka, M.: CFD and FEM Coupling Analysis of OREX Aerothermodynamic Flight Data. AIAA-1995-2087, 30th Thermophysics Conference, San Diego CA, Jun 1995.
2. Gupta, R.N.; Moss, J.M.; and Price, J.M.: Assessment of Thermochemical Nonequilibrium and Slip Effects for Orbital Reentry Experiment (OREX). AIAA-1996-1859, 31st Thermophyscis Conference, New Orleans LA, Jun 1996.

Data Collected by: C. Park

MISSION: **PATHFINDER**
"SOJOURNER"
PLANET: **MARS**

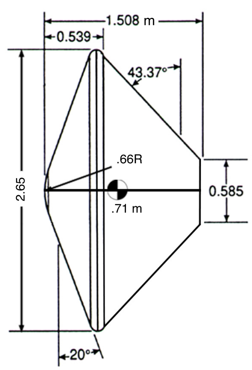
LAUNCH: DEC 4, 1996
ENTRY: JUL 4, 1997

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

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	Inertial −14.06°	*Shape*	70° sphere-cone	*Trim L/D (specify trim α)*	Ballistic (0° average)	*Material designation*	SLA-561V (SLA-561S-backshell)
Inertial entry velocity	7.26 km/s	*Nose radius*	0.66 m	*Ballistic coeff.*	At peak heat flux: 62.3 kg/m^2	*Thickness*	1.9 cm
Relative entry velocity	7.48 km/s	*Base area*	5.52 m^2	*Stagnation heating rate*	105.87 W/cm^2	*Ablating? Ejected?*	Ablating
Velocity at peak heat	Relative: 6.61 km/s	*Vehicle mass*	At entry: 585.3 kg	*Integrated heat load*	3864.5 J/cm^2	*Resin mat. Matrix mat.*	Resin
Control method	Ballistic	*TPS mass fraction, inc. insul.*	6.2% fore body; 2% back shell	*Radiative heat flux*	5.26 W/cm^2	*Resin dens. Matrix density*	
Center of Gravity, X_{CG}/D	.27	*Payload mass*		*PH stag. pressure*	.19 atm	*Total material density*	256.45 kg/m^3

INSTRUMENTATION:
- TPS instrumented with thermocouples only

NOTES:
- Spin stabilized



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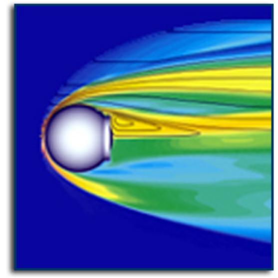
1. Spencer, D.A.; Blanchard, R.C.; Braun, R.D.; Kallemeyn, P.H.; and Thurman, S.W.: Mars Pathfinder Entry, Descent, and Landing Reconstruction. Journal of Spacecraft and Rockets, Vol 36, No 3, May-Jun 1999.
2. Milos, F.S.; Chen, Y.K.; Congdon, W.M.; and Thornton, J.M.: Mars Pathfinder Entry Temperature Data, Aerothermal Heating, and Heatshield Material Response. Journal of Spacecraft and Rockets, Vol 36, No 3, May-Jun 1999.

Data Collected by: G. Allen



MISSION: **MIRKA**
PLANET: **EARTH**

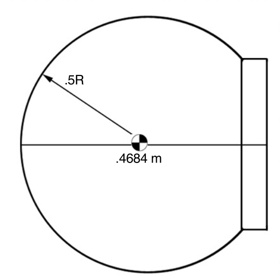
LAUNCH: OCT 9, 1997
ENTRY: OCT 23, 1997

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

Trajectory		Geometry		Aero/thermal		TPS	
Entry angle	Retative: -2.51°	*Shape*	Spherical 1 m diameter	*Trim L/D (specify trim α)*	0	*Material designation*	CFRP with SPA, and a fiber ceramic cover (see note)
Inertial entry velocity	Separation velocity: 7.3 km/s	*Nose radius*	.5 m	*Ballistic coeff.*	214 kg/m^3	*Thickness*	Front: 3 cm Back: 2 cm
Relative entry Velocity	7.6 km/s @ 120 km	*Base area*	.785 m^2	*Stagnation heating rate*	Peak: 120 W/cm^2	*Ablating? Ejected?*	Yes No
Velocity at peak heat	6.51 km/s	*Vehicle mass*	154 kg	*Integrated heat load*	12,000 J/cm^2	*Resin mat. Matrix mat.*	
Control method	Ballistic	*TPS mass fraction, inc. insul.*	36%	*Radiative heat flux*		*Resin dens. Matrix density*	
Center of Gravity, X_{CG}/D	.4584, (y: -.0002 z: .0002)	*Payload mass*		*PH stag. pressure*	.178 atm	*Total material density*	Virg. Ablator: 550 kg/m^3

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.



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1. Schmitt, G.; Pfeuffer, H.; Kasper, R.; Kleppe, F.; Burkhardt, J.; and Schöttle, U.M.: The MIRKA Re-entry Mission. IAF-98-V2.07, 49th Intl Astronautical Congress, Melbourne, Australia, Sep-Oct 1998.
2. Schmitt, G.; and Kasper, R.: MIRKA Micro Re-entry Capsule. IAF-94-V.2.532, 45th Intl Astronautical Congress, Jerusalem, Israel, Oct 1994.

Data Collected by: U. M. Schöttle