Instrument Host Overview - Spacecraft

Launch Vehicle Description

The launch vehicle used for Mars Pathfinder was the McDonnell Douglas Delta II 7925. An engine section in the Delta first stage housed the Rocketdyne RS-27 main engine and two Rocketdyne LR101-NA-11 vernier engines. The vernier engines provided roll control during main engine burn, and attitude control after main engine cutoff and before second stage separation. The RS-27 main engine was a single start, liquid bi-propellant rocket engine which provided approximately 894,094 N of thrust at lift off. The first stage propellant load (96,000 kg) consisted of RP-1 fuel (thermally stable kerosene) and liquid oxygen as an oxidizer. The RP-1 fuel tank and liquid oxygen tank were separated by a center body section that housed control electronics, ordnance sequencing equipment, a telemetry system, and a rate gyro. First stage thrust augmentation was provided by nine solid-propellant Graphite Epoxy Motors (GEMs), each fueled with 12,000 kg of hydroxyl-terminated polybutadiene solid propellant. Each GEM provided an average thrust of 439,796 N at lift off. The main engine, vernier engines, and six of the GEMs were ignited at lift off. The remaining three GEMs were ignited in flight. The GEMs were jettisoned from the first stage after motor burnout.

The interstage assembly extended from the top of the first stage to the second stage mini-skirt. This assembly carried loads to the first stage, and contained an exhaust vent and six spring driven separation rods.

The Delta II 7925 second stage propulsion system included a restartable, liquid bi-propellant Aerojet AJ10-118K engine that consumed Aerozine 50 fuel (a 50/50 mix of hydrazine and asymmetric dimethyl hydrazine) and nitrogen tetroxide (N2O4). Since Aerozine 50 and nitrogen tetroxide are hypergolic, no catalyst or igniter in the engine thrust chamber was required. The second stage had a total propellant load of 6000 kg and provided a thrust of 42,000 N. Gaseous helium was used for pressurization, and a nitrogen cold gas jet system provided attitude control during coast periods and roll control during powered flight. Hydraulically activated gimbals provided pitch and yaw control. The forward section of the second stage housed the guidance and control equipment that provided guidance sequencing and stabilization signals for both the first and second stages. Both first and second stages had a battery driven DC power system. Separate batteries were used for the guidance and control system, ordnance, and engine systems. The instrumentation and flight termination system were powered by the same battery.

The Payload Assist Module D (PAM-D) was the third stage of the Delta II 7925 launch vehicle and provided the final velocity required to place the Pathfinder spacecraft on a trajectory to Mars. The PAM-D upper stage consisted of (1) a spin table to support, rotate, and stabilize the Pathfinder spacecraft / PAM-D combination before separating from the second stage, (2) a Star-48B solid rocket motor for propulsion, (3) an active Nutation Control System (NCS) to provide stability after spin-up of the spacecraft/PAM-D stack, (4) a 3717C payload attach fitting to mount the Star-48B motor to the spacecraft, and (5) a yo-yo de-spin system designed to decrease the spin rate of the upper stage / spacecraft stack from 70 RPM to 12 +/- 2 RPM. The Star-48B provided an average thrust of 67,168 N and was fueled with 2000 kg of solid propellant that was composed primarily of ammonium perchlorate and aluminum.

During launch and ascent through the sensible atmosphere, the Pathfinder spacecraft / PAM-D upper stage combination was protected from aerodynamic forces by a 2.9 m diameter payload fairing. The payload fairing was jettisoned from the launch vehicle during second stage powered flight at a minimum altitude of 111 km.

Flight System Description

The Mars Pathfinder Flight System consisted of six major subsystems: Attitude and Information Management (AIM); Telecommunications; Entry, Descent, and Landing (EDL); Power and Pyrotechnics; Propulsion; and Mechanical Structure. Brief descriptions of the subsystems are given below.

Mechanical Structure

The Mars Pathfinder flight system was effectively three spacecraft in one. The flight system was a standard interplanetary spacecraft in one mode, an atmospheric entry vehicle in another, and a surface lander in the third. The major components of the spacecraft were the cruise stage, the entry vehicle (consisting of the heatshield, backshell, and attached hardware), and the lander (containing the rover). Components from all other subsystems were distributed through each of these elements.

The purpose of the lander was to provide engineering support to the science instruments and rover during surface operations. The landing approach employed by Mars Pathfinder required the lander to have self righting capability. A simple tetrahedron design was developed to limit the possible landing orientations. The lander was able to right itself if it landed on any face of the tetrahedron by driving actuators which connected three faces of the tetrahedron (the petals) with the fourth (the base petal). All thermally sensitive electronics were contained in the insulated Integrated Support Assembly (ISA) located inside the tetrahedron. This enclosure provided a controlled environment to minimize the effects of the extreme temperature variations on Mars. The lander high gain antenna and low gain antenna were attached to the outside of the ISA, as was the Imager for Mars Pathfinder. The rover was attached to one of the side petals.

A detailed description of the entry vehicle is given in the following EDL subsystem description. The cruise stage was responsible for controlling the vehicle during cruise, and was home to most of the components required for interplanetary flight. These included launch vehicle separation devices; attitude sensors; propulsive thrusters, tanks, and other equipment; cruise antennas; and solar arrays. The cruise stage was jettisoned prior to entry into the Martian atmosphere and impacted the surface. To eliminate duplication of capabilities, cruise stage hardware utilized key telecommunications, attitude and information management services, and power support from equipment that resided on the lander. As a result, there was a significant umbilical extending between the lander and cruise stage.

Entry, Descent, and Landing Subsystem

The Entry, Descent, and Landing subsystem was responsible for safely placing the lander on the surface of Mars. In order to do this, the velocity had to be reduced from the initial entry velocity of 7.6 km/s to a level that limited the maximum landing shock to less than 40 g's. Specific components of the system required to do this included a 2.65 meter diameter aeroshell, accelerometers, a parachute, an incremental bridle, retrorockets, airbags, and a radar altimeter.

The aeroshell was used to reduce the velocity of the vehicle from 7.6 km/s to .370 km/s, removing over 99% of the initial kinetic energy and protecting the lander against the resultant extreme aerodynamic heating. The heatshield was a Viking-heritage, 70 degree half angle blunt cone. Thermal protection was provided by Viking-heritage SLA-561V ablative material. Ablative material was also applied to the backshell to protect the lander from the effects of recirculation flow around the entry vehicle. During the entry and descent phases, accelerometers on the lander provided parachute deployment timing information and acceleration data. A 12.7 meter diameter Viking heritage disk-gap-band parachute was used for terminal descent. The parachute was designed to open at supersonic speeds with a maximum deployment dynamic pressure of 700 N/m^2.

The EDL system also included separation devices designed to separate the heatshield from the backshell after parachute deployment. The heatshield had to be separated and released from the backshell so that the lander could be deployed on the incremental bridle. The incremental bridle was designed to provide separation between the backshell-mounted retrorockets and the lander and to improve stability during the rocket firing. A radar altimeter on the lander was used to determine when to ignite the three retrorockets. The retrorockets were sized to bring the backshell/lander system to a complete stop at approximately 15 m above the surface. Four airbags attached to the faces of the tetrahedral lander were inflated just before the rockets fired and were designed to limit landing loads to less than 40 Earth g's. The airbags were inflated using three gas generators in 1/4 of a second. The generators continued to maintain the pressure in the airbags for over one minute past initial pressurization. Just prior to contacting the surface, cable cutters released the lander from the parachute, backshell, and retrorockets. The lander hit with a vertical velocity of 12 m/s and a horizontal velocity of 6 m/s. After ground impact and tumbling, the airbags deflated and were retracted. The three lander petals were then opened to establish an upright configuration on the surface.

All of the details of the timing for the entire EDL procedure were determined in real time on board the spacecraft.

Attitude and Information Management Subsystem

The AIM subsystem performed all spacecraft computing functions including command and telemetry handling, HGA pointing, payload data compression, cruise attitude determination and control, and EDL timing. This subsystem was built around a single high-performance (20 MIPS), 32-bit, single-board R6000 computer. The computer had 128 Mbyte of dynamic RAM for flight software, engineering measurements, and science data. An additional 4 Mbytes of electronically erasable PROM was included to hold flight software boot code, critical sequences and data. The speed and capabilities of this computer greatly simplified both software development and mission operations.

Internal interfaces within AIM were implemented using a VME bus backplane. Major VME interfaces included the Power & Pyrotechnics subsystem, the Reed Solomon downlink board, the hardware command decoder, and the power converter unit. A Mil-Std-1553 bus served for engineering data links to remote engineering units which collected status data from the celestial sensors and analog telemetry channels. Celestial sensors included a modified Magellan/IUS star scanner and a five head sun sensor. The spacecraft was spin stabilized during cruise, and maintained an Earth point profile for most of the flight (except for portions near Earth and Mars). The attitude determination and control system was required to maintain at least 2 degrees inertial pointing throughout cruise. Attitude determination and HGA control was required during the surface phase. The autonomous pointing accuracy requirement for the HGA was 3.5 degrees (note that more accurate pointing was possible using downlink dithering). The AIM was also responsible for collecting and packetizing science data from the instruments.

Flight software in the AIM controlled the uplink interface, downlink telemetry, instrument control, engineering / science data collection and formatting, bus control, sequence and command processing, attitude determination / control, and power / pyro functions. The flight software design was coded in 'C'. The operating system was an adaptation of VxWorks, a commercially-available operating system for the R6000 computer. The operating system provided a file system and an interprocess communications protocol for flight software components.

Telecommunications Subsystem

The Telecommunications subsystem provided communications capability during cruise, EDL and surface operations and support for radio navigation during cruise. The baseline design was a direct to Earth X-band system. There were two major elements to this subsystem: the Radio Frequency Subsystem (RFS) and the Antenna Subsystem. All RFS components were located in the lander ISA. Primary RFS functions were performed by a single string Cassini transponder, a 13 watt (RF) Solid State Power Amplifier, a newly developed Telemetry Modulation Unit, and a Cassini Command Decoder Unit. This single string approach was designed to work for the duration of the short Pathfinder mission, however, a partially redundant backup downlink capability was also provided. This backup system included a small X-band transmitter with an integrated 5 W (RF) power amplifier and an additional TMU. This backup provided significantly less performance than the primary system, but was designed to be sufficient to satisfy the primary mission objectives in an emergency.

The Antenna Subsystem consisted of five antennas for cruise, EDL and surface operations. A waveguide connected the RFS in the lander to a medium gain antenna (MGA) located on the cruise stage. A medium gain antenna was required to maintain a minimum 20 b/s link through cruise. The MGA was a standard Mars Observer design. Two antennas were provided for EDL communications. The backshell LGA was used during entry and early parachute descent. The EDL LGA was a whip antenna attached to the top of the lander and was used during the final portion of parachute descent. Two antennas were provided on the lander. The principal antenna was a steerable high gain antenna mounted on the ISA. The HGA was a mechanically-steered slotted plate with 2 degrees of freedom in pointing. It provided a nominal 125 b/s command uplink rate and a telemetry downlink rate of approximately 600 b/s into a DSN 34-m antenna (or 2700 b/s into a 70-m antenna). These data rate capabilities assumed 3.5 degrees pointing of the HGA. Improved pointing (using a dithering scheme with the DSN) could improve these rates. These rates were also conservative in that they contained a 3 dB link margin. A Low Gain Antenna was provided for emergency situations in the event the HGA should fail. The LGA provided an emergency 7.8 b/s command uplink rate and a minimum 40 b/s downlink rate over a 60 degree beam width.

Power and Pyrotechnics Subsystem

The Power and Pyrotechnics Subsystem was responsible for generating, storing and distributing power during cruise and surface operations. In addition, this subsystem was responsible for controlling and initiating all pyrotechnic devices required for EDL and surface operations. Power was generated during cruise by a 4.4 m^2 Gallium Arsenide (GaAs) solar array which covered the top surface of the cruise stage. The 5.5 mm thick cells were arranged to prevent any single failures from catastrophically impacting the power output. Power was generated on the surface by 2.9 m^2 of GaAs solar arrays mounted on the exposed surfaces of the lander petals. The lander and cruise stage used the same 5.5 mm thick cells.

A 40 amp-hr (~1120 W-hr @ 28 V) silver zinc battery was used to provide energy storage during the mission. Silver zinc batteries are typically used in primary battery applications (like launch vehicles), but Pathfinder re-qualified the technology for use as a rechargeable battery. The advantage of this type of battery is a much higher energy density than typical NiCd or NiH batteries. The disadvantage is a relatively short cycle life (limited to 30-100 cycles). The battery was only used to support launch, trajectory correction maneuvers (TCMs) and surface operations, however, so the cycle capability was sufficient for primary operations.

The power distribution system used an unregulated bus controlled by a shunt regulator. Pyro devices were initiated using a secondary power distribution system (isolated from the main) to prevent ground loop problems. Because of the rapid firing of pyros during EDL, special thermal batteries were included as a backup power source for the pyro system. The pyro system was designed to provide sufficient arm and enable controls to satisfy all system safety requirements.

Propulsion Subsystem

The Propulsion subsystem included all equipment needed to perform attitude control and TCM's during cruise and Rocket Assisted Deceleration during EDL. The cruise stage propulsion system consisted of four blow-down hydrazine titanium propellant tanks connected with eight 4.45 N (1 lb) thrusters via series latch valves. These thrusters were arranged to allow coupled turns and both axial and transverse translational maneuvers. The purpose and function of the RAD rockets are described more fully in the EDL section above.

Mass Summary

The spacecraft launch mass was 894 kg, including the hydrazine (N_2H_4) propellant, science instruments, and a free-ranging rover surface vehicle. The required amount of propellant was calculated using the maximum available spacecraft launch mass of 905 kg. The entry mass was 584 kg. The entry mass was a key driver on the EDL system design, so careful margin management was important.

Spacecraft Summary

Launch Mass: 894 kg (Includes Propellant)
Entry Mass: 584 kg
Lander Mass: 370 kg

Basic Design:
- Aeroshell, parachute, RAD rocket and airbag Entry, Descent, and Landing (EDL) system
- Self righting, tetrahedral lander
- Active thermal design for cruise
- Free ranging rover

Command And Data Handling
- Integrated Attitude and Information Management System (AIM)

Computation
- R6000 Computer with VME bus, 22 Millions of Instructions Per Second (MIPS), 128 Mbyte mass memory

Power
- Solar powered cruise stage and lander

Telemetry And Command
- Surface operations telemetry rate via High Gain Antenna (HGA), X-Band: 6 kb/s to 70 m Deep Space Network
- Surface operations command rate via HGA, X-Band: 250 b/s

Propulsion
- Monopropellant hydrazine used for cruise
- Eight 4.4 N thrusters

- Total delta-v of 130 m/s

Instrument Host Overview - DSN

The Pathfinder radio telecommunications system was used to monitor the distance between Earth and Pathfinder and its rate of change in order to determine the rate of precession of Mars. This utilized elements of the NASA Deep Space Network (DSN) in addition to the instrumentation on board the spacecraft.

The Deep Space Network is a telecommunications facility managed by the Jet Propulsion Laboratory of the California Institute of Technology for the U.S. National Aeronautics and Space Administration.

The primary function of the DSN is to provide two-way communications between the Earth and spacecraft exploring the solar system. To carry out this function the DSN is equipped with high-power transmitters, low-noise amplifiers and receivers, and appropriate monitoring and control systems.

The DSN consists of three complexes situated at approximately equally spaced longitudinal intervals around the globe at Goldstone (near Barstow, California), Robledo (near Madrid, Spain), and Tidbinbilla (near Canberra, Australia). Two of the complexes are located in the northern hemisphere while the third is in the southern hemisphere.

The network comprises four subnets, each of which includes one antenna at each complex. The four subnets are defined according to the properties of their respective antennas: 70-m diameter, standard 34-m diameter, high-efficiency 34-m diameter, and 26-m diameter.

These DSN complexes, in conjunction with telecommunications subsystems onboard planetary spacecraft, constitute the major elements of instrumentation for radio science investigations.