

THE MARS PATHFINDER MISSION

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ABSTRACT

Mars Pathfinder, one of the first Discovery class missions (quick, low-cost projects with focused science objectives), will land a single spacecraft with a microrover and several instruments on the surface of Mars in **1997**. Pathfinder will be the first mission to use a rover, carrying a chemical analysis instrument, to characterize the rocks and soils in a landing area over hundreds of square meters on Mars, which will provide a calibration point or "ground truth" for orbital remote sensing observations. In addition to the rover, which also performs a number of technology experiments, Pathfinder carries three science instruments: a stereoscopic imager with spectral filters on an extendible mast, an alpha proton X-ray spectrometer, and an atmospheric structure instrument/meteorology package. The rover technology experiments, the instruments and the telemetry system will allow investigations of: the surface morphology and geology at sub-meter to a hundred meters scale, the petrology and geochemistry of rocks and soils, the magnetic properties of dust, soil mechanics and properties, a variety of atmospheric investigations and the rotational and orbital dynamics of Mars. Landing downstream from the mouth of a giant catastrophic outflow channel, Arcs Vallis at 19.5°N, 32.8°W, offers the potential of identifying and analyzing a wide variety of crustal materials, from the ancient heavily cratered terrain, intermediate-aged ridged plains and reworked channel deposits, thus allowing first-order scientific investigations of the early differentiation and evolution of the crust, the development of weathering products and early environments and conditions on Mars.

INTRODUCTION

Despite humankind's great fascination with Mars [Kieffer et al., 1992], Pathfinder will be the first spacecraft to land on the Red Planet since the Viking landers more than 20 years ago [Snyder and Moroz, 1992]. The landing of Mars Pathfinder on July 4, 1997 will initiate an exciting era of Mars exploration and will be followed closely by the arrival of the Mars Global Surveyor orbiter and the Russian Mars '96 spacecraft (consisting of an orbiter, two small landers, and two penetrators) in September 1997. The scientific objectives of the Mars Global Surveyor

orbiter are to systematically characterize the atmosphere, surface and interior over one martian year. The Mars '96 orbiter has similar objectives, but also will characterize the uppermost atmosphere and its interaction with the solar wind. As such, these missions will provide a remote sensing characterization of the entire surface of Mars. The Russian landers will also provide first-order characterization of the atmosphere and surface at the few point locations where they land. Mars Pathfinder, however, will be the first mission to explore in detail a landing area on Mars with a mobile platform capable of measuring the chemical composition of surface materials. Because of this mobility, it will be able to explore a landing area that is of order hundreds of square meters (as opposed to a few square meters accessible by lander-mounted mechanical arms). Pathfinder's instruments and rover will provide a characterization of martian rocks and surface materials over a substantial area, thereby providing "ground truth" for humankind's view of Mars that is currently based mostly on global remote sensing data.

The Mars Pathfinder Project received a new start in October 1993 as the next mission in NASA's long term Mars exploration program. The spacecraft is a novel design that combines the cruise, entry, descent and landing functions into a single "free-flyer". The project is one of the first Discovery-class missions, which are low cost (\$150M development cost cap - fiscal year 1992 dollars, excluding launch vehicle, rover and mission operations), short development (about 3 years) missions that have a set of significant, but focused engineering, science, and technology objectives. The primary objective of Pathfinder is to demonstrate a low-cost cruise, entry, descent, and landing system that can safely place a payload on the martian surface. Additional objectives include the deployment and operation of the science instruments and of a microrover (which costs an additional \$22M in fiscal year 1992 dollars). Pathfinder paves the way for a cost effective implementation of future Mars lander missions. The Mars Surveyor '98 lander that is under development extensively uses Pathfinder components and systems, including the aeroshell, heat shield, parachute, flight computer and software, aspects of the command and data handling systems, and the solid-state power amplifier; the Mars Surveyor '98 orbiter also uses much of Pathfinder's computer system. The Jet Propulsion Laboratory (JPL) of the California Institute of

Technology, which is NASA's lead center for the robotic exploration of the solar system, built and manages the Pathfinder spacecraft and rover, with most subsystem components contracted out to industry. Existing flight qualified hardware has been used wherever possible to reduce cost; this has also increased the mass of the spacecraft.

This paper provides a brief introduction to the Mars Pathfinder mission and spacecraft. First, the flight system and mission are briefly described. A general description of the instruments is followed by an overview of the scientific objectives and investigations. Mission operations and data management are then briefly described along with mention of the Mars Pathfinder landing site. More detailed papers on the specific instruments and rover and their detailed science and technology investigations are included in this volume [Smith et al., Rieder et al., Stiff et al., The Rover Team]. A companion paper [Golombek et al., this issue] provides a more detailed description of the capabilities of the landing system, the landing site and the selection process.

MISSION AND SPACECRAFT OVERVIEW

Spacecraft Description

The Pathfinder flight system (Figure 1 and Plates 1 and 2) consists of three major elements: the cruise stage, the deceleration subsystems, and the lander (containing the rover and science instruments). The current spacecraft launch mass is approximately 890 kg (100 kg of this is cruise stage fuel), including about 25 kg of payload, consisting of science instruments, rover and rover support equipment.

The cruise stage is used to perform launch vehicle separation, spin-stabilized attitude control, trajectory correction maneuvers, cruise telecommunications, and final Mars entry attitude placement. The cruise stage is jettisoned prior to entry into the martian atmosphere. Cruise stage hardware consists of a gallium arsenide solar array (4.4 m² generating 250-450 W of power) and additional related power equipment, a medium gain X-band antenna, propulsion valves, tanks, and thrusters, and attitude determination sensors (Magellan star scanner); it weighs 205 kg without fuel.

Deceleration subsystems are required to reduce Pathfinder's entry velocity and allow a safe landing on the martian surface. The deceleration subsystems consist of a Viking-heritage aeroshell (or heatshield) and backshell, engineering instrumentation used to characterize the performance of the aeroshell during entry, a Viking-heritage disk-gap-band parachute, an incremental bridle, three small solid retrorockets, a radar altimeter, and airbags, all of which weighs 310 kg. The retrorockets and airbags provide a robust landing system (e.g., Golombek et al., this issue), with minimal surface and atmospheric contaminant ion due to propellant effluents.

The 275 kg lander is a tetrahedron-shaped structure containing the science instruments, rover, anti all electronic and mechanical devices required to operate on the surface of Mars (Plate 2). The tetrahedron consists of four similarly shaped 1 m triangular panels. All lander equipment except the solar arrays, rover, and meteorology mast are attached to a single center panel. The other three panels are attached to the edges of the center panel by actuators that are used to right the lander after touchdown, which can be accomplished regardless of which panel the lander comes to rest on. This active self-righting mechanism is needed because of the passive nature of the Pathfinder deceleration subsystems. All thermally sensitive electronics are contained in an insulated enclosure on the center panel, including: a high-performance central computer that controls the spacecraft during cruise, entry, descent, landing and surface operations (a 32-bit radiation hardened workstation-RAI 6000 with roughly a gigabit of memory, programmable in C with a VxWorks operating system); a Viking-heritage transponder; a solid-state power amplifier for telecommunications; and a high-capacity rechargeable battery (40 amp-hr). Hardware outside the thermal enclosure includes a steerable high-gain X-band antenna capable of approximately 5.5 kilobits per second into a 70 m Deep Space Network antenna and panel mounted solar arrays (3.3 m² gallium arsenide array generating 1100 W-hr/day) capable of providing enough power to transmit for 2-4 hours per sol (a martian day, 24.6 hours) and maintain 128 megabytes of dynamic memory through the night.

Mission Overview

Pathfinder will be launched on a McDonnell Douglas Delta 11792.5 expendable launch vehicle in December 1996 from the Cape Canaveral Air Station in Florida. The launch period opens December 2, 1996 and remains open for about 30 days, with one window per day available for launch (2:10 am EST on December 2, 1996). The spacecraft is injected into a Type II Earth-Mars transfer trajectory on a Payload Assist Module-D upper stage within one Earth orbit. Arrival at Mars is fixed on July 4, 1997.

The 6-7 month cruise phase is relatively quiescent, including periodic attitude control maneuvers required to remain Earth pointed, and four trajectory correction maneuvers needed to ensure accurate arrival at Mars. The spacecraft is spin stabilized at about 2 rpm; the solar arrays remain within 40° of perpendicular to the Sun. Spacecraft engineering status data are transmitted by a medium gain antenna throughout cruise. No science investigations are conducted during cruise (all instruments are enclosed within the folded-up lander), but science instrument and rover health checks are performed twice.

At Mars arrival, the cruise stage is jettisoned and the spacecraft orients itself for atmospheric entry at an angle of 14.2° from horizontal, directly from the hyperbolic approach trajectory at a velocity of 7.65 km/s (Figure 2). The lander enters the atmosphere within the aeroshell (heatshield) and backshell with a ballistic coefficient of about 62 kg/m², which helps slow the vehicle (peak deceleration of about 20 g's at 30 km altitude). The aeroshell is heated and jettisoned just prior to parachute deployment at Mach 1.8 at 6-10 km altitude. During spacecraft descent on the parachute, which has a terminal velocity of about 60 m/s, the lander is lowered beneath the backshell on a 20 m long bridle. A radar altimeter, mounted in one of three triangular openings at the base of the lander, triggers firing of three small solid tractor rockets (~2 s burn) about 50 m above the surface (Figure 2 and Plate 3). The rockets eliminate the vertical velocity of the lander, but not the horizontal velocity. Giant six-lobed air-bags inflate around each face of the lander (see Figure 1 in Golombek et al. [this issue]). The bridle is cut prior to final rocket burn, ensuring that the parachute and backshell are carried away. The air-bags are not vented during

landing (peak decelerations of 40 g's), so that the lander bounces a number of times before coming to rest, with the first bounce being up to 80% of the original drop height (-12 m). The random nature of these bounces will carry the lander to a location uncontaminated by solid rocket exhaust, which is composed mostly of aluminum oxide. Accelerometers signal that the lander has come to rest, at which time interior filtered peel-away patches vent the airbags, with minimal surface contamination (airbag gas generators produce solid carbon soot and sal-ammoniac, NH_4Cl). The lander accelerometers determine which panel the lander is resting on and automatically instruct the upper airbags to retract (internal tendons pull the airbags close to the panels) and the panels to open in the proper sequence to assure an upright configuration. Key entry, descent and landing events are signaled by modulating the transmitted spacecraft signal. In addition, all engineering and science data obtained during the entry, descent, and landing phase are recorded for playback at the initiation of lander surface operations. The duration of the entry phase is approximately 5 minutes. Landing occurs in darkness, very early in the morning at about 3:14 am local Mars time, just after Earth rise. Opening of the lander takes a few hours before the spacecraft can be commanded from the Earth (about 7 am local Mars time).

The highest priority activities on the landing sol are to achieve an upright landed configuration (Figure 3), return the recorded entry science and engineering data, establish a high-rate telecommunications link, acquire and return a panoramic image of part of the surrounding terrain, and drive the rover off its petal safely onto the surface (Figure 4). Surface operations for the remainder of the 30 sol prime mission arc focused on extensive use of the rover and science instruments. The prime rover mission is 7 sols, with operations funded for up to 30 SOIS. Lander mission operations are budgeted for up to one Earth year in length.

Mars Pathfinder will land within a 100 km by 200 km ellipse (resulting from navigational and ephemeris uncertainties during cruise and at atmospheric entry) in Arcs Vallis, Chryse Planitia (19.5°N, 32.8°W). This site lies just downstream from the mouth of the Arcs and Tiu Valles catastrophic outflow channels, which drained from the highlands to the south. Selection of this site was made after consideration of: engineering constraints derived from the spacecraft and rover

designs (both of which are particularly robust) and the entry, descent and landing scenario; site safety inferred from a suite of remote sensing observations (including high-resolution imaging, radar reflectivity and roughness, thermal inertia, rock abundance, albedo and red (o violet ratio); and science potential described in the companion paper by Golombek et al. [this issue.]. Landing at this site (a so called "grab bag" site) offers the prospect of sampling a diversity of rock types that make up the ancient heavily cratered terrain on Mars, the ridged plains and a variety of reworked channel materials. Examination of these materials allows the prospect for addressing first-order scientific questions such as the primary differentiation and] early evolution of the crust, the development of weathering products and the early environments and conditions on Mars. Even though the exact provenance of the samples will not be known, data from subsequent orbital remote sensing missions will then be used to infer the provenance for the samples studied by Pathfinder.

Rover

The rover on Mars Pathfinder (Plates 2 and 4) is a small, six-wheel drive "rocker bogie" design vehicle, which is 65 cm long by 48 cm wide by 30 cm high. Total mass of the rover is about 10.5 kg (including payload); lander support equipment adds another 5.5 kg. The rocker bogie chassis provides a very stable platform for mounting instruments and has demonstrated remarkable mobility, including both the ability to climb obstacles that are a full wheel diameter in height and the capability of turning in place. The vehicle communicates with the lander via a UHF antenna link and will operate almost entirely within view of the lander cameras, or within a few tens of meters of the lander. Extended mission traverses up to 100 m from the lander are possible, limited by the UHF link. It is a solar powered vehicle (0.25 m² solar panel generating 16 W peak power) with a primary battery back-up (~300 W-hr), which moves at ~0.4 m/min, and carries 1.5 kg of payload. The payload includes monochrome stereo forward cameras for hazard detection and terrain imaging (Figure 3, Plate 4) and a single rear color camera. The Alpha Proton X-ray Spectrometer (APXS) is mounted on a deployment device at the rear of the vehicle (Figure 3) that will allow placement of the APXS sensor head up against both rocks and soil at wide range of

orientations (from horizontal on the ground to vertical rock faces at rover height), The rear facing camera will image the APXS measurement sites at slightly better than 1 mm per pixel resolution. The rover control system includes a variety of autonomous hazard detection systems (such as forward laser light stripers for detecting obstacles or crevasses and potentiometers for detecting bogie tilts) for safing the vehicle in potentially hazardous situations. General scientific guidance for the rover has been provided by an appointed Rover Scientist, H. J. Moore of the U.S. Geological Survey, Menlo Park.

The rover will also perform a number of technology experiments designed to provide information that will improve future planetary rovers. These experiments include: terrain geometry reconstruction from rover imaging; dead reckoning, path reconstruction and Vision sensor performance vehicle performance; rover thermal characterization; UHF link effectiveness; basic soil mechanics by imaging wheel tracks and sinkage and monitoring vehicle performance data such as motor torques and bogie positions; material abrasion by sensing abrasion of different thicknesses of paint on a rover wheel; and material adherence by measuring dust accumulation on a reference solar cell with a removable cover and by directly measuring the mass of the accumulated dust on a quartz crystal microbalance [The Rover Team, this issue].

MARS PATHFINDER SCIENTIFIC INSTRUMENTS

Imager for Mars Pathfinder (IMP)

The Imager for Mars Pathfinder (IMP) was designed and built by P. Smith of the University of Arizona following selection as a Principal Investigator (P.I.) experiment through a NASA Announcement of opportunity. In addition to the camera hardware, the investigation includes a variety of calibration, color, and magnetic properties targets and wind socks [Smith et al., this issue]. The instrument was developed under a cost- and mass-capped contract.

The stereoscopic imager is deployed on an extendible mast (Figure 3) to a height of roughly 1.5 m above the surface (0.85 m above the lander). The imager is fully operational in both the pre-deployed and post-deployed states, which provides a large vertical stereo baseline. It includes two

three-element lenses, two fold mirrors separated by 15 cm for stereo viewing, a 12-channel filter wheel in each path, and a fold prism to place the images side-by-side on a single CCD focal plane. Fused silica windows at each path entrance prevent dust intrusion. The optical triplets are an $f/10$ design, stopped down to $f/22$ with 23-mm effective focal lengths and a 14.4° field of view. The focal plane consists of a CCD mounted at the foci of two optical paths. Its image section is divided into two square frames, one for each half of the stereo pair. Each of the stereo frames has 248×256 active elements. The pixel instantaneous field of view is one milliradian. Most filters are for geologic studies and stereo viewing (12 filters with narrow bandpasses between 0.4 and 1.1 microns, which are particularly sensitive to iron oxide and pyroxene composition), others for measuring atmospheric water vapor and aerosols and a magnifying close-up lens [Smit et al., [this issue]]. Azimuth and elevation drives provide a nearly complete view of the lander, martian surface and sky.

A magnetic properties investigation is being provided by an IMP Co-Investigator (Co-I) J. M. Knudsen of the Niels Bohr Institute, University of Copenhagen (this and other foreign contributions are at no cost to the project). Two sets of 5 magnets of differing field strengths are mounted on the lander in view of the IMP, one set is on top of the thermal enclosure and the other set is on the base plate near the surface (Figure 3). A magnet is also mounted on a plate directly beneath the imager, which will be viewed through a magnifying lens. Magnets at the ends of the rover deployment ramps are also included as potential sites for measuring the elemental composition of the magnetic dust (Plate 4). The IMP investigation also includes the observation of wind direction and speed, using 3 small wind socks provided by Co-IR. Greeley of Arizona State University, mounted on the meteorology mast at three different heights (Figure 3, Plates 2 and 4).

calibration and reference targets include (Figure 3) 2 radiometric calibration targets, with shadow posts, and 4 color targets mounted on the spacecraft (with each magnetic and calibration target) and 2 on the rover (along the edge of the solar panel). 1 MP Co-I's not mentioned above include: D. Britt, L. Doose, R. Singer, and M. Tomasko of the University of Arizona; L. Soderblom of the U.S. Geological Survey, Flagstaff; H. U. Keller of the Max Planck Institut für

Aeronomie, who is providing the CCD and associated electronics; and F. Gliem of the Technical University of Braunschweig, who is providing the image compression software. The JPL Investigation Scientist, K. 1 Ierkenhoff, provides the main scientific interface between the P.J. and the project.

Alpha Proton X-Ray Spectrometer (APXS)

This instrument is a foreign-provided derivative of an instrument design flown on the Soviet Vega and Phobos missions and is identical (o those being flown on both small stations of the Russian Mars '96 mission [Rieder et al., this issue,]. The alpha and proton spectrometer portions are provided by the Max Planck Institut für Chemie, Mainz, Germany, under the direction of R. Rieder, P.J. and H. Wänke, Co-I. The X-ray spectrometer portion and the integration of the instrument on the rover is being provided by T. Economou of the University of Chicago. The JPL investigation Scientist is J. Crisp.

The APXS determines elemental chemistry of surface materials for all major elements except hydrogen. The analytical process is based on three interactions of alpha particles with matter: elastic scattering of alpha particles by nuclei, alpha-proton nuclear reactions with certain light elements, and excitation of the atomic structure of atoms by alpha particles, leading to the emission of characteristic X-rays. The approach used is to expose material to a radioactive curium source in the sensor head that produces alpha particles with a known energy, and to acquire energy spectra of the alpha particles, protons and X-rays returned from the sample.

The basis of the alpha mode of the instrument is the dependence of the energy spectrum of alpha particles scattered from a surface on the composition of the material. The method has the best resolving power for the lighter elements. The proton spectra for alpha particles interacting with elements with atomic numbers from 9 to 14 are very characteristic of these individual elements. The addition of a third detector for X-rays results in a significant extension of the accuracy and sensitivity of the instrument, particularly for the heavier, less abundant elements. The instrument is sensitive to elemental concentrations of a tenth to a hundredth of a percent.

The APXS sensor head is mounted external to the rover chassis on a deployment mechanism (Figure 3) that allows the instrument to be placed in contact with both rock and soil surfaces at a wide variety of elevations and angles. Springs in the deployment device allow about 20° of compliance as the sensor head is placed against a sample, which is signaled by a series of contact sensors. The APXS electronics are mounted within the rover, in a temperature-controlled environment.

Atmospheric Structure Instrument / Meteorology Package (ASI/MET)

The ASI/MET has been implemented as a facility experiment, developed by JPL, to provide engineering support to the measurement of tile entry, descent and landing conditions and to acquire atmospheric structure and meteorology data both before and after landing [Stiff et al., this issue]. A NASA-appointed Science Advisory Team, under the leadership of A. Sieff (NASA Ames Research Center/San Jose State University) provided scientific guidance to the JPL instrument team. Members of this appointed team included J. Barnes (Oregon State University), D. Crisp (JPL), R. Jaberle (Ames Research Center), and J. Tillman (University of Washington). The JPL investigation Scientist is J. T. Schofield.

The accelerometer portion of the ASI is provided by the Attitude and Information Management (AIM) subsystem of the spacecraft. It consists of x-, y-, and z-axis accelerometers with several gain states provided to cover the wide dynamic range from micro-g accelerations experienced upon entering the atmosphere to peak decelerations during landing of up to 40 g's. The AIM also includes three engineering accelerometers (one mounted on the x-axis and two in the y-z plane oriented at 45° to the z-axis) that are identical to the science accelerometers. None of the accelerometers is exactly on the center of gravity of the spacecraft.

Other ASI/MET hardware consists of temperature, pressure and wind sensors and an electronics board for operating the sensors and digitizing their output signals. Temperature is measured by thin wire thermocouples mounted on a 1 m high meteorological mast that is deployed at the far end of a petal to minimize thermal contaminant ion from the lander (Figure 3). Four thermocouples are arrayed on the mast. One is mounted at the end of the ASI/MET_{mast}, so that

when it is folded against the petal it measures the temperature of the atmosphere during descent in a triangular hole at the base of the lander. Three other thermocouples placed near the top, midway and one quarter from the bottom of the meteorology mast will measure tile temperature at 3 heights above the surface during the landed mission. Pressure is measured by a Tavis magnetic reluctance diaphragm sensor similar to that used by Viking. A tube from tile sensor, within tile central electronics box, to the same triangular hole at the lander base where the descent temperature sensor is located allows measurement of pressure during descent and after landing (Figure 3). The wind sensor employs six hot wire elements distributed uniformly around the top of the mast, which allow measurement of wind speed and direction (from the temperatures of the elements).

MARS PATHFINDER SCIENCE OBJECTIVES AND INVESTIGATIONS

The science payload described above, used in conjunction with selected engineering subsystems aboard both the lander and rover, provide the opportunity for a number of scientific investigations. The scientific objectives and investigations afforded by Pathfinder include: surface morphology and geology at sub-meter to a hundred meters scale, elemental composition and mineralogy of surface materials, a variety of atmospheric science investigations, and rotational and orbital dynamics investigations from two-way ranging and Doppler tracking of the lander.

The surface imaging system will reveal martian geologic processes and surface-atmospheric interactions at a scale currently known only at the two Viking landing sites. It will observe the general physiography, surface slopes and rock distribution in order to understand the geological processes that created and modified the surface. This will be accomplished by panoramic stereo imaging before and after the imager deploys on its extendible mast and at various times of the day. Observations over the life of the mission will allow assessment of any changes in the scene over time that might be attributable to frost, dust or sand (imposition, erosion or other surface-atmosphere interactions). The rover will also take close-up images of the terrain, soil and rocks during its traverses. An understanding of near-surface stratigraphy and soil mechanics and properties will be obtained by rover and lander imaging of rover wheel tracks, holes dug by rover

wheels, and any surface disruptions caused by airbag bounces or retraction (in retraction tests, rocks were dragged along the surface forming furrows).

The APXS and the visible to near infrared spectral filters on the imaging system will determine the elemental composition and constrain the mineralogy of rocks and other surface materials, respectively, thereby addressing questions concerning the composition of the crust, its differentiation and the development of weathering products. These investigations will provide a calibration point ("ground truth") for orbital remote sensing observations. The imaging system will obtain full multispectral panoramas of the surface and any near-surface strata exposed during roving and landing. Because the APXS is mounted on the rover it will characterize the composition of rocks and soil in the vicinity of the lander (samples selected over hundreds of square meters), which will represent a significant improvement in our knowledge over that obtained by Viking. The rover-mounted APXS sensor head on Pathfinder will also be placed in holes dug by the rover wheels and against rocks that have been abraded by a rover wheel. Multispectral images are also planned for the magnetic targets distributed at various points (and heights) around the spacecraft, which will be used to discriminate the magnetic phase of accumulated airborne dust over time. In addition, APXS measurement of magnetic targets on the rover ramps will determine the titanium and iron content of the dust, which are important for distinguishing the various magnetic phases. The forward stereo and rear color imagers on the rover will enable close-up images of APXS measurement sites with slightly better than 1 mm per pixel resolution. Between these images and auxiliary information from lander imaging spectra, it is likely that the mineralogy and petrology of rock samples can be deduced from the elemental abundances measured by the APXS.

The atmospheric structure instrument will determine a pressure, temperature and density profile of the atmosphere from about 120 km altitude to the surface during entry and descent at a location, time and season that are new relative to the 2 Viking profiles. Redundant three-axis accelerometers will allow extraction of atmospheric pressure during entry. Measurements of pressure and temperature will be made during descent. Diurnal variations in the atmospheric

boundary layer will be characterized by making regular surface meteorology measurements (pressure, temperature, atmospheric opacity, and wind). Both phases of the ASI/MET investigation seek to better understand the physical state and dynamics of the martian atmosphere. Thermocouples, mounted on a meter-high mast located on a petal away from the thermal enclosure, will determine the temperature profile with height. Wind speed and direction versus height in the boundary layer will be determined by a wind sensor on top of the mast, along with 3 wind socks on the mast; these data will also allow calculation of aerodynamic roughness of the surface, which is important for understanding the forces acting on small particles and their entrainment in the wind. Regular sky and solar spectral observations by the IMP will monitor aerosol particle size and shape, distribution with altitude, and refractive index, as well as the atmospheric water vapor abundance.

By two-way X-band range and Doppler tracking of the Mars Pathfinder lander by the Deep Space Network, a variety of orbital and rotational dynamics science objectives will be addressed. Ranging involves transmitting a ranging code to the lander and measuring the time required for the lander to echo the code back to the station. Dividing this time by the speed of light results in an accurate measurement of the distance from the station to the spacecraft. Typical noise for X-band ranging results in a range measurement uncertainty of 1-5 meters. To collect range data, the lander is required to be in the coherent tracking mode, the range channel on the transponder must be turned on, and the tracking station must be uplinking a carrier. In addition, as the lander moves relative to a tracking station, the velocity between the two causes a shift in the observed frequency. Two-way Doppler is produced by measuring the received frequency of the downlink carrier and comparing it to the uplink carrier frequency, which is stable and well known. The observed frequency shift in the downlink carrier provides a means of accurately measuring the range rate from the station to the lander. Within a few months of such tracking, it is expected that the location of the Pathfinder lander can be determined to within a few meters [Folkner et al., this issue]. With the location of the lander known, the pole of rotation of the planet can be determined. Knowledge of the orientation of the pole of rotation allows calculation of the precession rate to a fraction of a

percent by comparing with similar measurements made with the Viking landers about 20 years ago. Measurement of the precession rate (regular motion of the pole with respect to the ecliptic) allows direct calculation of the moment of inertia, which is governed by the density distribution with depth of the planet [e. g., Yoder and Standish, this issue.]. At present, the moment of inertia of Mars is poorly known and interior models with and without a metallic core cannot be distinguished. Measurement of the moment of inertia by Pathfinder tracking will provide strong constraints on possible interior models and will likely distinguish between these competing interior models. The present day moment of inertia is also a strong constraint on potential obliquity variations in the past [Folkner et al., this issue], which could have been large for Mars. Constraining possible obliquity variations is important for understanding long term climatic fluctuations. The seasonal variations in rotation rate (changes in length of day) are also indicative of the cycling of volatiles between the atmosphere and poles and can be addressed if Pathfinder can be tracked for a significant fraction of an Earth year. Finally, the ranging data can be used to address scientific questions regarding asteroid masses, the time variability of the gravitational constant, and can be used to test general relativity.

The scientific aspects of the development portion of the Mars Pathfinder mission have been directed by the Mars Pathfinder Project Science Group. This group is chaired by the Mars Pathfinder Project Scientist, M. Golombek, with vice-chair J. Boyce (NASA Headquarters Program Scientist). Members of this group include: P. Smith (IMP P.I.), R. Rieder (APXS P.I.), '1'. Economou (U.S. APXS Co-I), A. Stiff (ASI/MET SAT Leader), and H. Moore (Rover Scientist). This group changes membership somewhat, with the last two positions being terminated at release of a NASA Announcement of Opportunity for selection of Mars Pathfinder Participating Scientists and an ASI/MET Facility instrument Science Team and leader. The rotational and orbital dynamics science objective was developed at the request of the Project Scientist after the payload and developmental science teams had formed by an ad hoc group of scientists interested in this topic [B. Bills (Goddard Space Flight Center), '1'. Eubanks (U.S. Naval Observatory), W. Folkner (JPL.), R. Preston (JPL.), and C. Yoder (JPL.)].

MISSION OPERATIONS

The basic requirements for operating the lander and rover on the surface of Mars for a short period of time (one week to a month), with daily uplinks that are dependent on the previous day's downlinks, requires streamlined and efficient mission operations and ground data systems. This is made possible by an extremely capable central computer on the lander, a simplified set of spacecraft commands, some autonomous aspects of the rover and instruments, and development of integrated software packages that streamline generation of uplink commands. During operations the project management structure will be simplified considerably to include a group of spacecraft engineers (mostly development experts in navigation, propulsion, thermal control, power and pyres, telecommunications, etc.) and an Experiment Operations Team that includes all science, instrument and the rover team members collocated at JPL, directly under a single mission director.

operating the lander immediately after landing on the first sol is particularly challenging. Entry, descent and landing data are sent back via the low-gain antenna after landing and attaining an open operational configuration (including deployment of the ASI/MIT mast). After sunrise (7-8 am local time) and uplink from the Earth, the IMP camera is unlatched, searches for the sun, and provides the coordinates to the central computer, which determines the orientation of the lander and instructs the high-gain antenna to unlatch, point towards the Earth, and establish communications. The IMP takes a series of images of a portion of the lander, including the rover and a partial color panorama before deployment. After receipt of these data on Earth the rover ramps are instructed to unfurl. Images are taken to confirm deployment of the ramps after which the rover is detached from the petal, rotates its wheels to reach a full deployed configuration ("stands up") and is instructed to drive off the lander on one of the ramps. If all goes nominally, the rover will obtain an APXS measurement of the soil during the night following the first day. The final downlink of the day includes IMP images of the rover and the surface. After completing acquisition of an initial set of panoramas (one of which is downlinked on the first day), the IMP is deployed on its mast at the end of the first day.

operation of the lander and rover during the first week involves daily uplink and downlink sessions and involves obtaining data to support virtually all scientific and rover technology experiments and investigations. IMP stereo images will provide the three dimensional data base required to drive the rover and multi spectral images of the scene will help select APXS measurement sites. However, because the IMP can generate data much faster than it can be downlinked, careful choices must be made between full panoramic imaging desired to characterize the landing site and more spatially limited spectral data to identify interesting targets for the APXS near the lander early in the mission. The significant storage capability of the lander central computer allows sophisticated data acquisition and playback strategies for obtaining time critical engineering and science data during the mission.

Pathfinder has a minimum of 4 hours per day use of the 34 m and 70 m DSN antennas for uplink and downlink, respectively, during the one month prime mission. For expected high-gain antenna links, Pathfinder can return roughly 20-40 megabits of data per day, with a total data return over the first month of order 1 gigabit. Data return of this magnitude is capable of providing all the science, technology experiment and engineering data needed to fully satisfy all the science objectives and investigations discussed earlier (although a few months of tracking is required to determine the precession rate). The rover, with all its engineering, technology and science sensors is likely to produce of order a few megabits of data per day. After the first month, Pathfinder will use the 34 m antennas (which provide roughly a factor of 4 lower data rates), which should provide at least 3 uplink sessions per week and significant downlink capability (a few hours per day), thereby significantly augmenting the prime mission data return by a few megabits per day.

Virtually all of the scientific investigations and many of the rover technology investigations described earlier can be addressed by data from more than one instrument. The need for data from one or more instruments to address a particular science topic has driven mission operations to be organized around scientific investigations. The Experiment Operations Team will be composed of the traditional instrument and rover teams, but will also include Science Operations Groups. These groups will interface with the science instrument and rover teams in order to obtain the

observations required (each group may obtain data from more than one source). Rover technology experimenters will also participate in these groups as appropriate. Examples of Science Operations Groups, the data sources they might use, and the appropriate participation by rover technology experimenters are described below.

Surface Morphology and Geology Science Operations Group is interested in understanding the physiography and geologic evolution of the landing site, including surface features, slopes and physical characteristics. This group will use imaging from both the IMP and rover and might include participation by the terrain geometry reconstruction technology experimenters.

Petrology and Geochemistry Science operations Group will use IMP spectral imaging to target APXS measurements of rocks, soil and surface materials. Close-up imaging by the rover (forward stereo and rear color) cameras should help identify the rock type and can be used to help deduce the mineralogy of rocks.

Magnetic Properties Science operations Group will use multispectral imaging of magnetic targets, magnified close-up imaging of the tip plate magnet and APXS measurements of the ramp magnets to better understand the magnetic phase of the dust, its chemical composition and ultimately help constrain its mineralogy and origin.

Soil Mechanics and Properties Science operations Group will use stereo and close-up lander and rover imaging of rover wheel tracks and rover motor currents and voltages to estimate the mechanical and physical properties of the soil. Information relevant to this topic will include data from the vehicle performance, material abrasion and the soil mechanics and sinkage technology experiments.

Atmospheric Science Operations Group may be broken down into a number of subgroups according to their main focus. One group may be interested in reconstructing the atmospheric profile during entry and descent. Another group may characterize the diurnal and seasonal variations in the boundary layer by regular meteorology measurements including pressure, temperature, wind from the ASI/MET and from IMP observations of opacity and of wind socks. A group focusing on atmospheric aerosols may use data from the IMP to investigate aerosol size

and shape, vertical distribution, and refractive index, as well as water vapor abundance. in the atmosphere and may use data from the material adherence technology experiment. Finally, an aerodynamic roughness subgroup may use data from the wind socks, wind sensors and IMP and rover terrain imaging to better understand how material is lifted from the surface and carried by the wind.

Rotational and Orbital Dynamics Science Operations Group will use two-way ranging and Doppler tracking data from the Pathfinder telecommunications subsystem and Deep Space Network to determine the location of the Pathfinder lander on Mars, the pole and rotation of the planet and the precession rate.

DATA MANAGEMENT

All engineering, rover and science data returned by the Mars Pathfinder mission will be placed into the Project Data Base. Mars Pathfinder encourages rapid dissemination of data for education, public outreach, and publication of scientific results from the mission by the investigators. Although there is no proprietary period for any data returned by Pathfinder, science instruments data is subject to a short 6 month calibration and validation period, after which it will be deposited in the Planetary Data System for archival and use by the entire scientific community. During the calibration and validation period, the use, dissemination and publication of science data is under the discretion of the Principal Investigator or Team Leader.

SYNERGY WITH OTHER MARS MISSIONS

Mars Pathfinder is the first of three spacecraft planned to arrive at Mars in 1997. With its landing site at the mouth of two outflow channels, Pathfinder has the potential for characterizing the rocks that make up a significant fraction of the ancient highlands and ridged plains of the Xanthe Terra region of Mars (on the eastern edge of the Tharsis province, south of the landing site.). As a result, one of the most important objectives for the subsequent orbital remote sensing aspects of the Mars Global Surveyor (MGS) and Mars '96 missions is to determine the provenance

of the samples analyzed by Pathfinder. Provinces can be established by comparing the rock types observed by Pathfinder with spectral characteristics of areas within the drainage basin using the imagers and spectrometers on MGS and Mars '96. By doing so, Pathfinder may be able to provide the geologic "ground truth" for the wide drainage areas of Arcs and Tiu Valles. In addition, higher resolution images from MGS and Mars '96 of the landing area may be useful for determining the location of the lander (with respect to surface features) and its local geological environment, given that the highest resolution Viking images of the landing site are only 38 m/px.

It is possible that one or both of the MGS and Mars '96 orbiters will be making observations after they arrive in middle September 1997 while Pathfinder is still operating on the surface. If this occurs a variety of scientific observations can be planned that mostly involve using Pathfinder surface instruments to look up at atmospheric aerosols using the IMP or measure near-surface atmospheric temperature and pressure using the ASI/MET at the same time that orbiter instruments are looking down through the atmosphere of Mars. These coordinated observations allow better separation of near-surface boundary layer effects or surface effects (such as ground temperature) from those higher in the atmosphere. Comparison can also be made between surface-atmosphere interactions seen from orbit and those observable on the surface. Pathfinder may also be operating on the surface at the same time that the Russian small stations and penetrators are functioning. Thus, a mini-network of meteorology stations could be operating on the surface at the same time that imagers and spectrometers are probing the atmosphere and looking at the surface. Pathfinder measurements will also significantly improve our knowledge of the martian atmosphere to the benefit of MGS during its aerobraking into its mapping orbit. The ASI/MET instrument will have measured an atmospheric profile a few months before MGS arrives, thereby improving knowledge of the uppermost atmosphere. In addition, MGS is susceptible to short-term variations in uppermost atmosphere density during aerobraking; these variations appear to occur at the beginning and during dust storms. Pathfinder will provide hourly measurements of pressure, temperature and atmospheric opacity, which should quickly and readily alert MGS to the beginnings of a dust storm for planning during this period.

SUMMARY

Mars Pathfinder, one of the first Discovery class missions, will place a lander, rover and several scientific instruments on the surface of the Red Planet in July 1997. The spacecraft is a single integrated vehicle consisting of a simple back-pack-style cruise stage, a backshell and aeroshell of Viking heritage and a novel tetrahedral lander. The spacecraft enters the martian atmosphere directly behind the aeroshell and slows itself using a parachute, small solid rockets and a number of airbags. The lander petals open, righting the vehicle and exposing solar panels for power. Three science instruments, the rover and associated support equipment and technology experiments are included in the payload. The science instruments are: a stereo imaging system on an extendible mast with a variety of spectral filters; an alpha proton X-ray spectrometer (mounted on the rover); and an atmospheric structure instrument/meteorology package. The surface imaging system will be used to understand the geologic processes and surface-atmosphere interactions at a scale currently known only at the two Viking landing sites. Together, the alpha proton X-ray spectrometer will measure the elemental composition of surface materials, and the spectral filters on the imaging system and rover close up imaging will be used to infer the petrology and the mineralogy of rocks and surface materials, **which** can be used to address questions concerning the composition of the crust, its differentiation, the development of weathering products and early environmental conditions on Mars. Deposition of airborne dust over time on a series of small magnets on the lander is designed to distinguish the magnetic component of the martian dust. The atmospheric structure instrument will determine a pressure, temperature and density profile of the atmosphere (with respect to altitude) during entry and descent. Diurnal variations of the atmospheric boundary layer will be characterized by regular surface meteorology measurements. In addition, the imager will determine the characteristics and distribution of aerosols and atmospheric water vapor abundance from sky and solar spectral observations. Tracking of the lander over time will determine the location of the lander, the orientation of the pole of rotation, the precession rate and the moment of inertia of Mars, which will help constrain the size and density of any central metallic core.

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FIGURE AND PLATE CAPTIONS

Figure 1. Exploded view of Mars Pathfinder flight system, showing back-pack-style cruise stage, backshell with three solid rockets, tetrahedral lander, and aeroshell (heatshield). Diameter of spacecraft is **2.65** m.

Figure 2. Diagram illustrating Mars Pathfinder entry descent and landing scenario, Cruise stage separation occurs about 30 min before entry. Atmospheric entry occurs at about 125 km altitude, 4 min before landing with the vehicle traveling 7.6 km/s. Parachute deploys at about 8 km altitude, 3 min before landing, with the vehicle traveling at -400 m/s. The lander is lowered on the bridle about 80 s before landing, dropping at about 80 m/s. Airbags inflate **8 s** prior to landing, with the lander at terminal parachute velocity of -60 m/s. Landing occurs after the solid rockets fire and the bridle is cut. After bouncing and coming to rest, the airbags are automatically retracted and the petals (panels) open, righting the vehicle. The lander is in an operational configuration about 3 hours after landing.

Figure 3. Perspective view of lander opened on the surface showing the location of the instruments and rover. Descent temperature sensor is located on the end of the ASI/MET mast, which when folded against the petal is adjacent to the ASI/MET pressure tube located in indicated triangular space between the lander panels. Calibration or photometric targets are located at two heights on top of the electronics enclosure and on the lander base plate. Color targets are located at each of the IMP photometric targets, each of the magnetic targets, and along each side of the rover solar panel.

Plate 1. Picture of the Mars Pathfinder flight spacecraft in the cruise configuration as it appeared in the Spacecraft Assembly Facility (SAF) at the Jet Propulsion Laboratory in March 1996. Solar panels on top of cruise stage are beneath red protective cover shown; the white backshell and the rim of the tan aeroshell are also in view. Note gold covered propellant tanks and silver thruster cluster. Spacecraft attaches to the launch vehicle at the launch vehicle adapter (the top-most white cylinder).

Plate 2. Picture of the flight lander, with one petal open (with rover), as it appeared in SAF in late February 1996. Rover is in its stowed configuration (accomplished by flattening the rear bogie) mounted on its petal with rolled up rover ramps shown. Note white electronics box, with IMP in its stowed configuration (white horizontal cylinder). Silver rod extending to top of lander triangular opening is the low-gain antenna. ASI/MET mast is shown on edge of folded petal to the right. Note three wind socks dangling from mast (compare actual flight socks with other renditions in Figure 3 and Plate 4). Person to right is Tommaso Rivellini, Air Bag Cognizant Engineer; person to left is Linda Robeck, ATLO (Assembly, Test, Launch and Operations) engineer in charge of lander- integration. Solar cells on petals are covered by a protective film.

Plate 3. Artists rendition of Pathfinder landing on Mars in darkness early in the morning on July 4, 1997 (courtesy of Pat Rawlings, SAIC). Picture shows perspective view above backshell and disk-gap-band parachute after solid rockets on the inside of the backshell have fired (notice slack in the parachute lines), illuminating the surface. The tether to the lander has been cut, the airbags are inflated and the lander is rebounding from its initial impact (notice dust on bags and in atmosphere). Solid rocket burn after release of the lander coupled with the bouncing of the lander ensure that the parachute and backshell will fall to the surface away from the, lander and that the landing site will be free from solid rocket exhaust.

Plate 4. Artists rendition of lander and rover exploring the surface of Mars (courtesy of Mike Carroll). Rover ramps are shown unfurled allowing rover egress from the lander petal (note magnetic targets at the end of the ramps). Bar on front of rover houses two monochrome cameras (providing stereo views in front of the rover) and laser light strippers for autonomous hazard avoidance,.

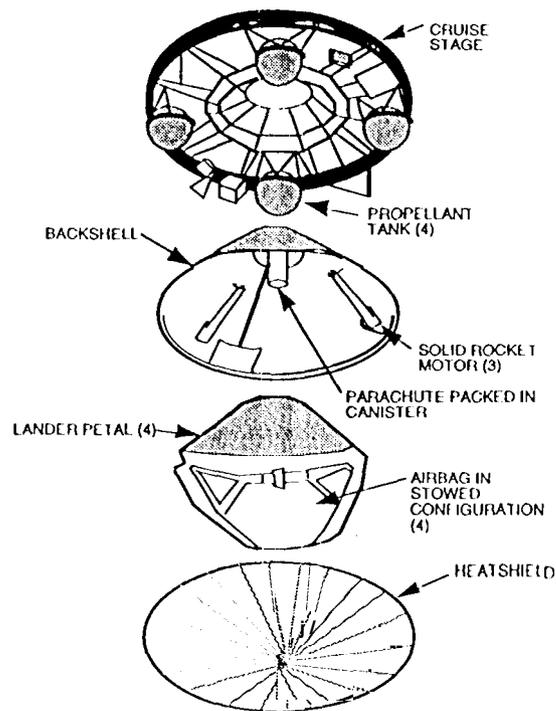


Figure 1.

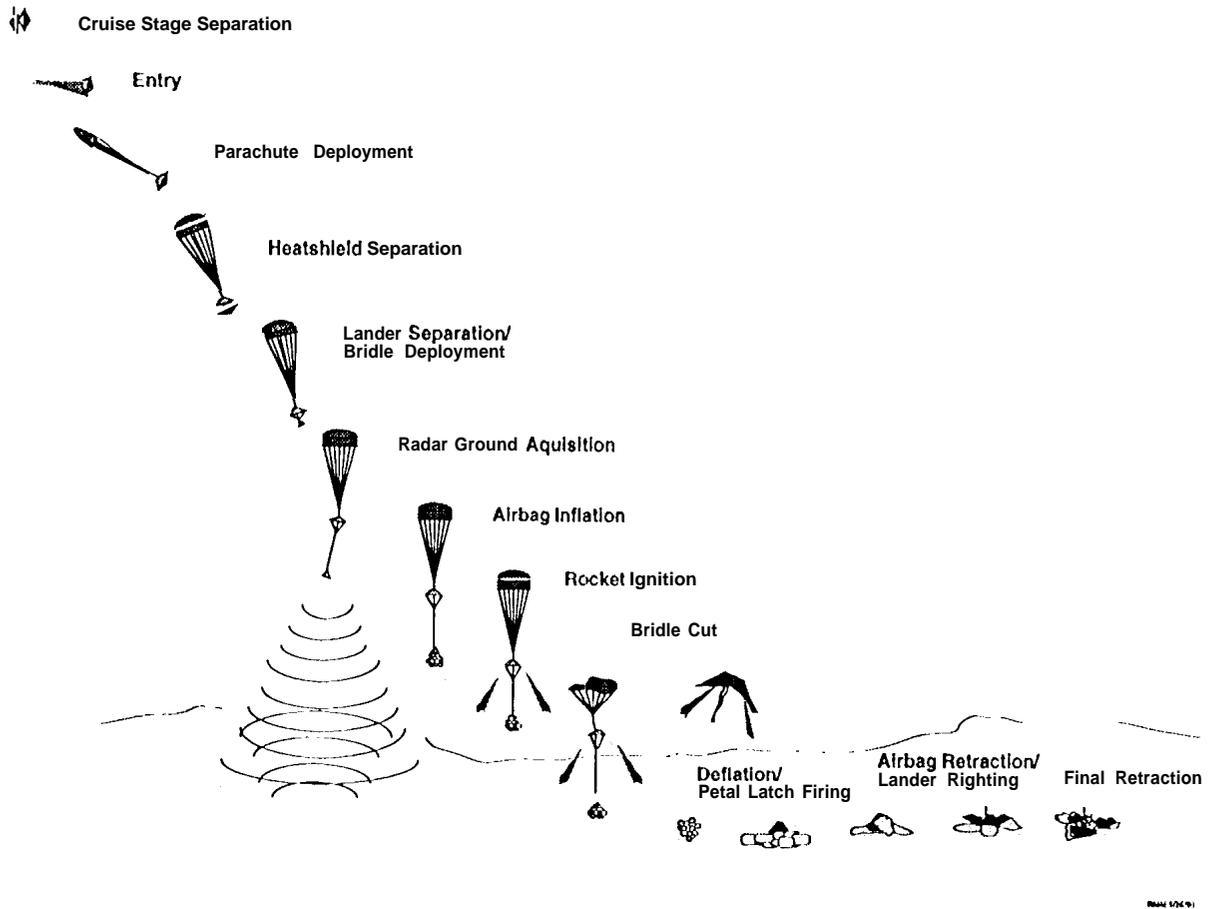


Figure 2.

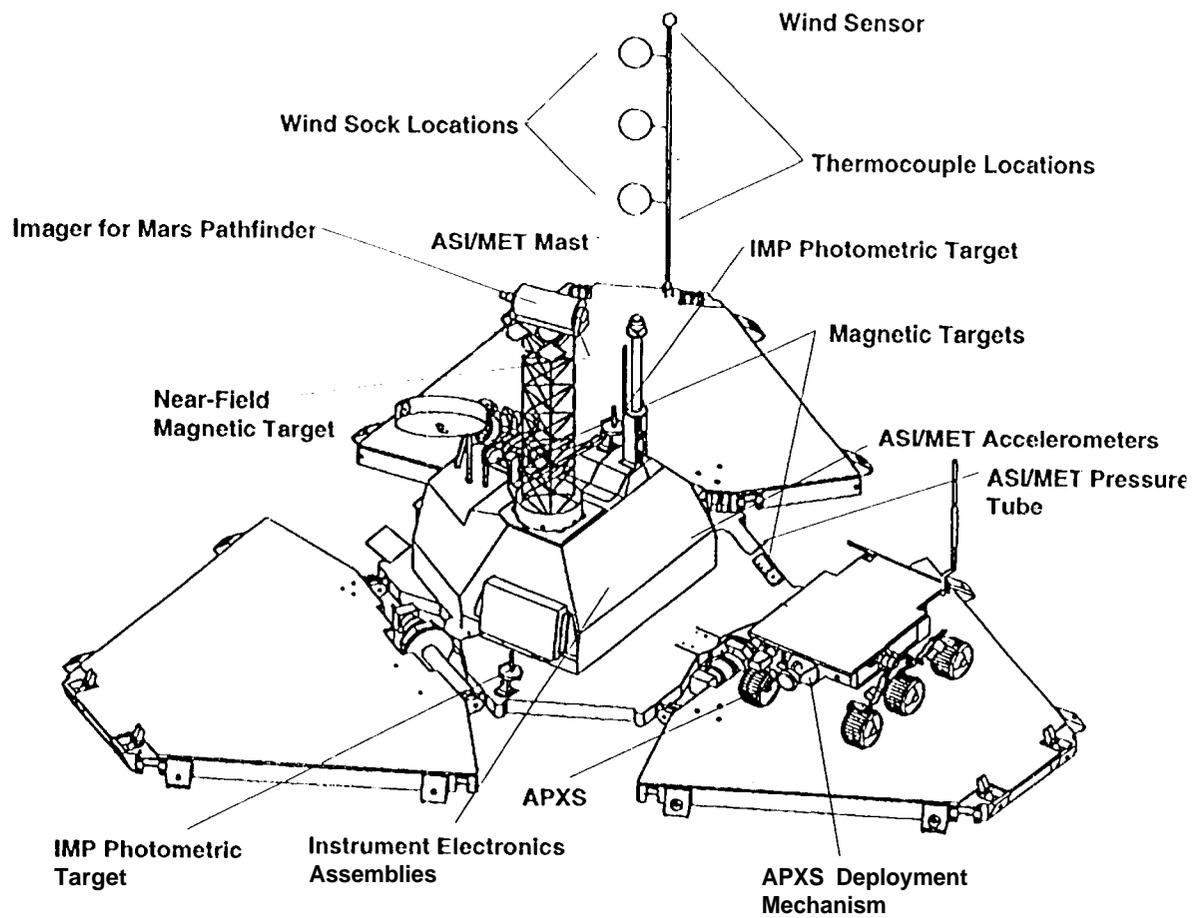


Figure 3

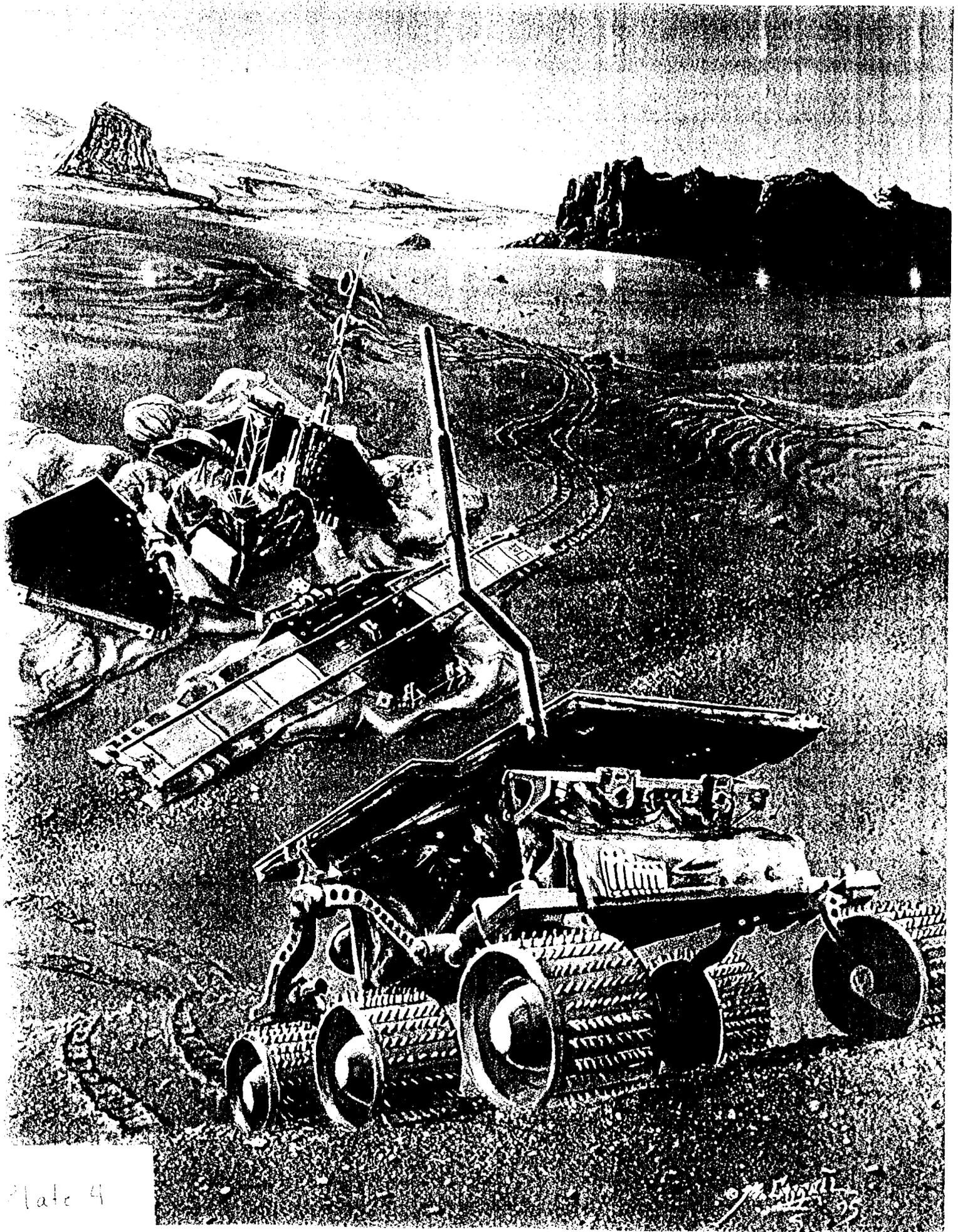
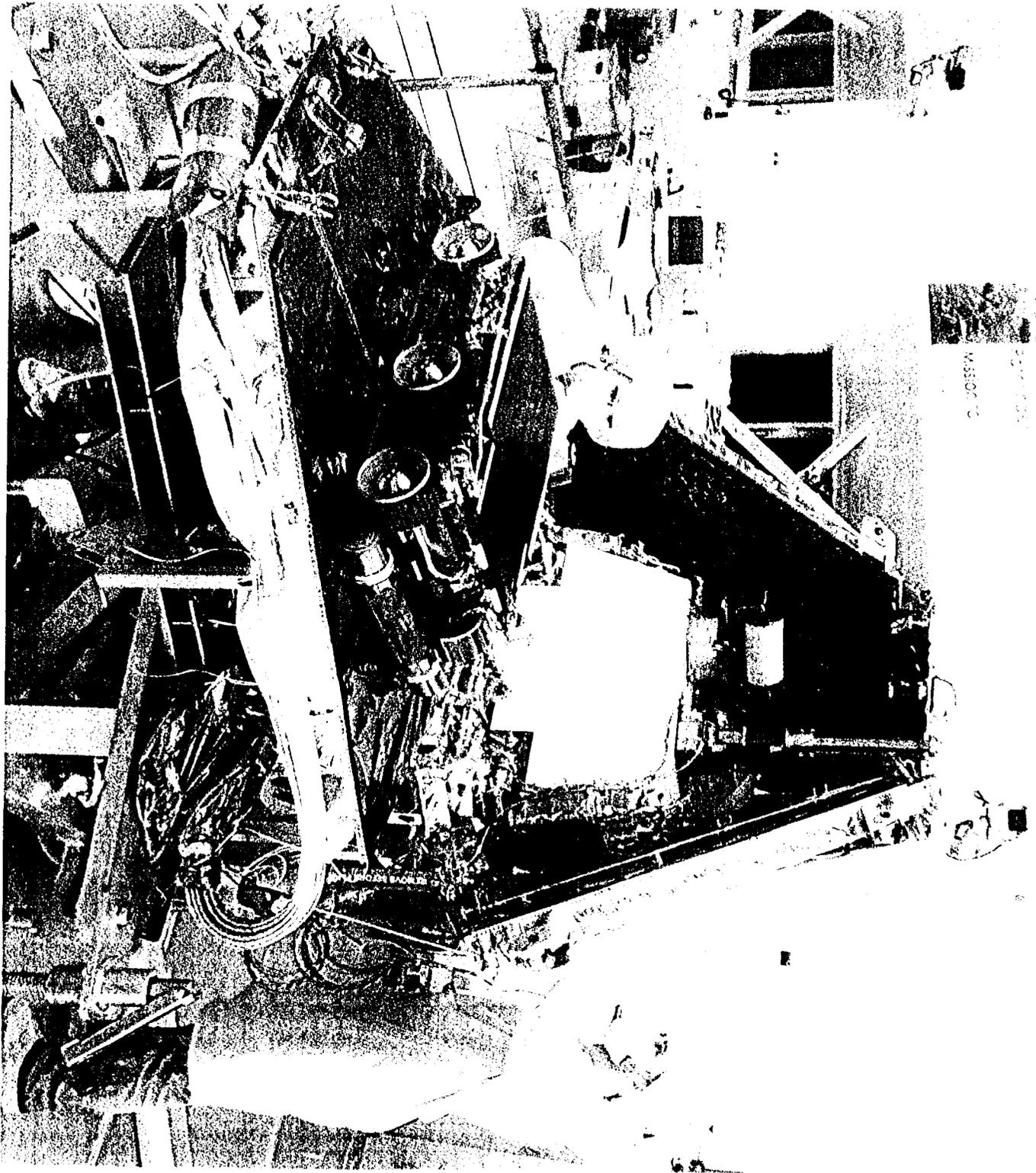


Plate 4

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