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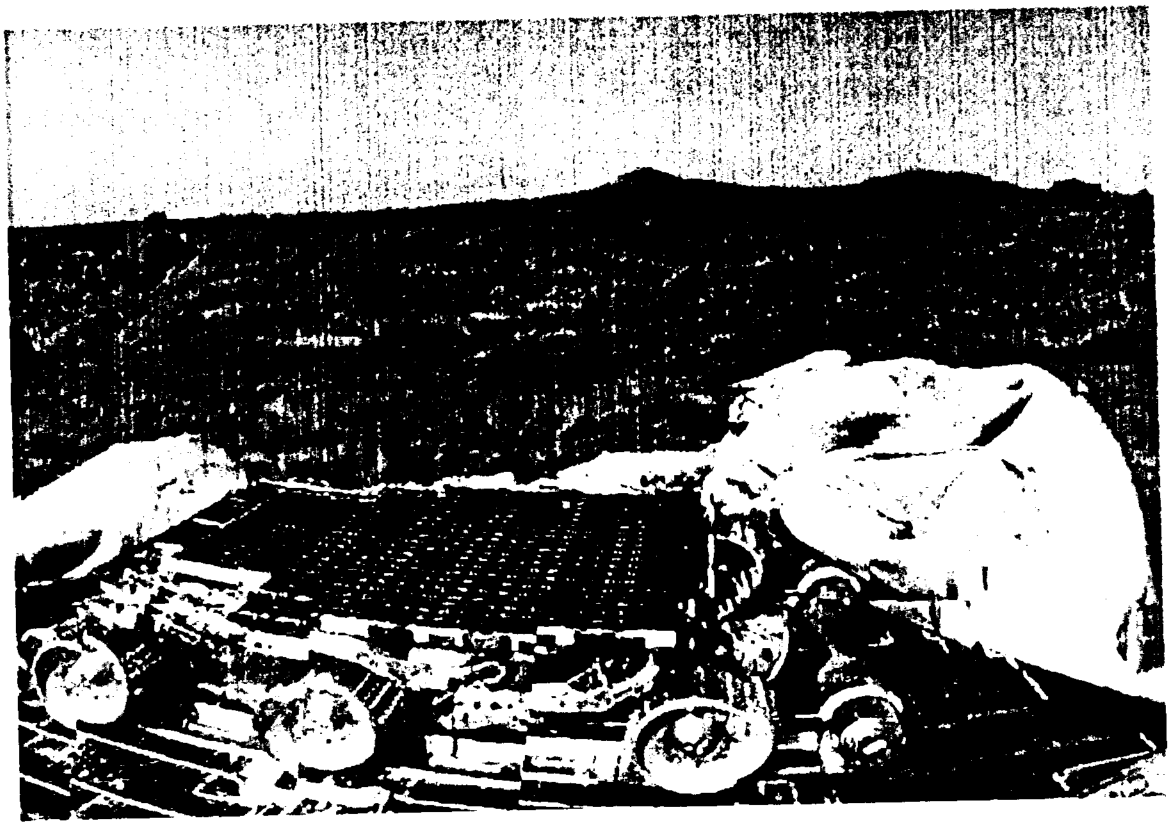

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# THE MARS PATHFINDER MISSION

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On July 4th, 1997, Mars Pathfinder became the third spacecraft to successfully land on the planet Mars. The mission's primary objective was to demonstrate a low-cost system for delivering a small science payload to the surface of Mars, and to test the operation of a rover. Scientific objectives include the characterization of the geological and elemental composition of rocks and soil near the lander, imaging, and measurement of the temperature and pressure during descent and at the surface. The Sojourner microrover is capable of traversing tens of meters from the lander to analyze rocks and soil in the immediate area. The lander's primary mission is 30 Martian days (30 Sols) after landing, with an extended mission lasting for onc year. This paper describes the science instruments, the spacecraft and the rover, and a summary of the flight operations history from launch through the second day on the surface.

## introduction

Mars Pathfinder is a part of NASA's Discovery program, which includes missions designed to accomplish focused scientific objectives within a development period of less than 36 months and a total cost through launch plus 30 days of $150 million or less (FY92$). The other missions within the Discovery program are the Near Earth Asteroid Rendezvous (NEAR) mission, the Lunar Prospector and the Stardust comet coma sample return mission. The last mission to successfully land and observe the Martian surface was Viking in 1976. Mars Pathfinder will complete its mission as a cost of 1/20 that of Viking.

Mars Pathfinder's primary mission was to demonstrate a simple, low-cost system for placing a science payload on the surface of Mars. Pathfinder's total cost will be $280 million dollars, including development of the lander and rover, the launch vehicle and mission operations through the end of August, 1998. The microrover (named "Sojourner") will demonstrate the mobility and usefulness of a microrover on the surface of Mars, and lead toward the further development of long-range rover designs now being planned for the Mars Surveyor 2001 mission and a Mars sample return mission in 2005.

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## Science Objectives

Pathfinder will be investigating the surface of Mars with a payload of three science instruments and the rover (Figure 1). The instruments will permit the investigation of the geology and surface morphology at scales ranging from sub-meter to hundreds of meters, the geochemistry and petrology of soils and rocks, the magnetic and mechanical properties of surface materials, a variety of atmospheric investigations, and rotational and orbital dynamics of Mars. The landing site offers the potential for identifying and analyzing a wide variety of crustal materials, from the ancient heavily cratered terrains to intermediate-aged ridged plains to reworked channel deposits. Examination of the different surface materials will allow first-order scientific investigations of the early differentiation and evolution of the crust, the development of weathering products and the early environments and conditions that have existed on Mars.

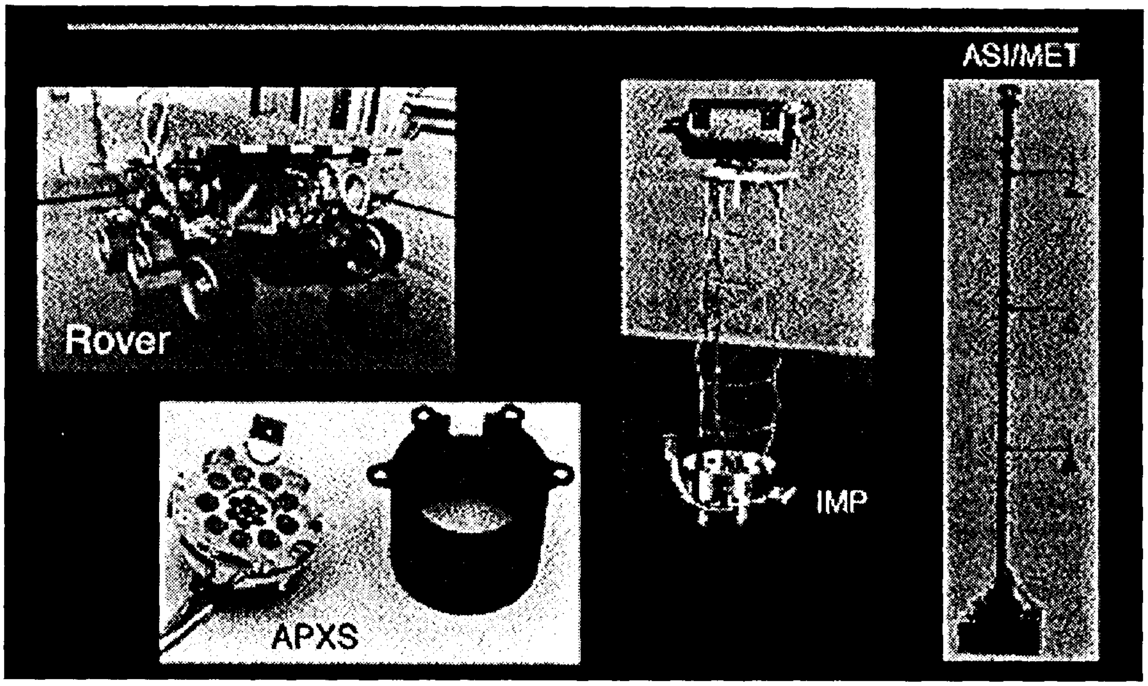


Figure 1: Mars Pathfinder science instruments

The Imager for Mars Pathfinder (IMP) will reveal martian geologic processes and surface-atmosphere interactions at the surface of Mars. Observation of the general landscape, surface slopes and the distribution of rocks will be obtained by panoramic stereo images at various times of the day. Any changes in the scene over the lifetime of the mission might be attributed to the actions of frost, dust or sand deposition, erosion or other surface-atmosphere interactions. A basic understanding of the surface and near-surface soil properties will be obtained by the rover and lander imaging of rover wheel tracks, holes dug by the rover wheels, and any surface disruptions caused by airbag bounces or retractions.

The Alpha-Proton X-Ray Spectrometer (APXS) and the visible to near-infrared spectral filters on the IMP will determine the elements that make up the rocks and other surface materials of the landing site. A better understanding of these materials will address questions concerning the composition of the martian crust, as well as secondary weathering products (such as different types of soils). These investigations will provide a calibration point for orbital remote sensing observations such as Mars Global Surveyor. The IMP will be able to obtain full multi-spectral panoramas of the surface and underlying materials exposed by the rover and lander. Since the APXS is mounted on the rover, it will be able to characterize rocks and soils in the vicinity of the lander.

Magnetic targets are distributed at various points around the spacecraft. Multi-spectral images of these targets will be used to identify the magnetic minerals which make up airborne dust. In addition, APXS measurement taken of the material collected on the magnetic targets will determine the presence of titanium and iron in the dust. Using a combination of the images, and APXS measurements, it is possible that the mineral that make up the rocks can be inferred. Detailed examination of the wheel-track images will give a better understanding of the mechanics of the soil surrounding the landing site.

The Atmospheric Structure Instrument/Meteorology (ASI/MET) experiment will be able to determine the temperature and density of the atmosphere during Entry, Descent and Landing (EDL). In addition, three-axis accelerometers will be used to measure atmospheric pressure during this period. Once on the surface, meteorological measurements such as pressure, temperature, wind speed and atmospheric opacity will be obtained on a daily basis. Thermocouples mounted on a meter-high mast will examine temperature profiles with height. Wind direction and speed will be measured by a wind sensor mounted at the top of the mast, as well as three wind socks interspersed at different heights on the mast, Understanding this data is very important for identifying the forces which act on small particles carried by the wind. Regular sky and solar spectral observations using the IMP will monitor windborne particle size, particle shape, distribution with altitude and the abundance of water vapor.

To address a variety of martian orbital and rotational dynamics questions, two-way X-Band Doppler and ranging data from the lander will be collected from Earth-based tracking stations. Once the exact location of Pathfinder has been identified, the orientation and precession rate of the pole can be calculated and compared to measurements made with the Viking landers 21 years ago. Measurement of the precession rate allows direct calculation for the moment of inertia, which is in turn controlled by the density of the martian rock with depth. Measurements similar to these may answer long-standing questions regarding the makeup of the interior of the planet.

## Landing Site

Mars Pathfinder's selected landing site is at 19.5 N latitude and 32.8 W longitude in an area known as Ares Vallis, a rocky plain at the mouth of an ancient outflow channel (Figure 2). This landing site was chosen from among several different candidate sites at a workshop attended by over 60 scientists in 1994. The site is 850 kilometers (527 miles) southeast of the location of the Viking 1 Lander.

Ares Vallis met the engineering constraints for a low elevation site at approximately 20° North latitude. The northern latitude site allows for higher Earth and Sun elevation angles during the martian day, permitting longer contact times with Earth and optimum solar power performance. A low elevation area was preferred to maximize the probability of a successful parachute descent and landing. The area is also relatively free of craters, chasms and other features that might pose a hazard to the spacecraft upon landing.

Scientifically, Ares Vallis was chosen for the variety of rock and soil samples it may present. The site is set at the mouth of a large outflow channel in which a wide variety of rocks are potentially within the reach of the rover. The rocks would have been washed down from highlands at a time when floods moved over the surface of Mars. Even though the exact origins of the samples might not be known, the chance of sampling a variety of rocks in a small area will reveal a lot about Mars.

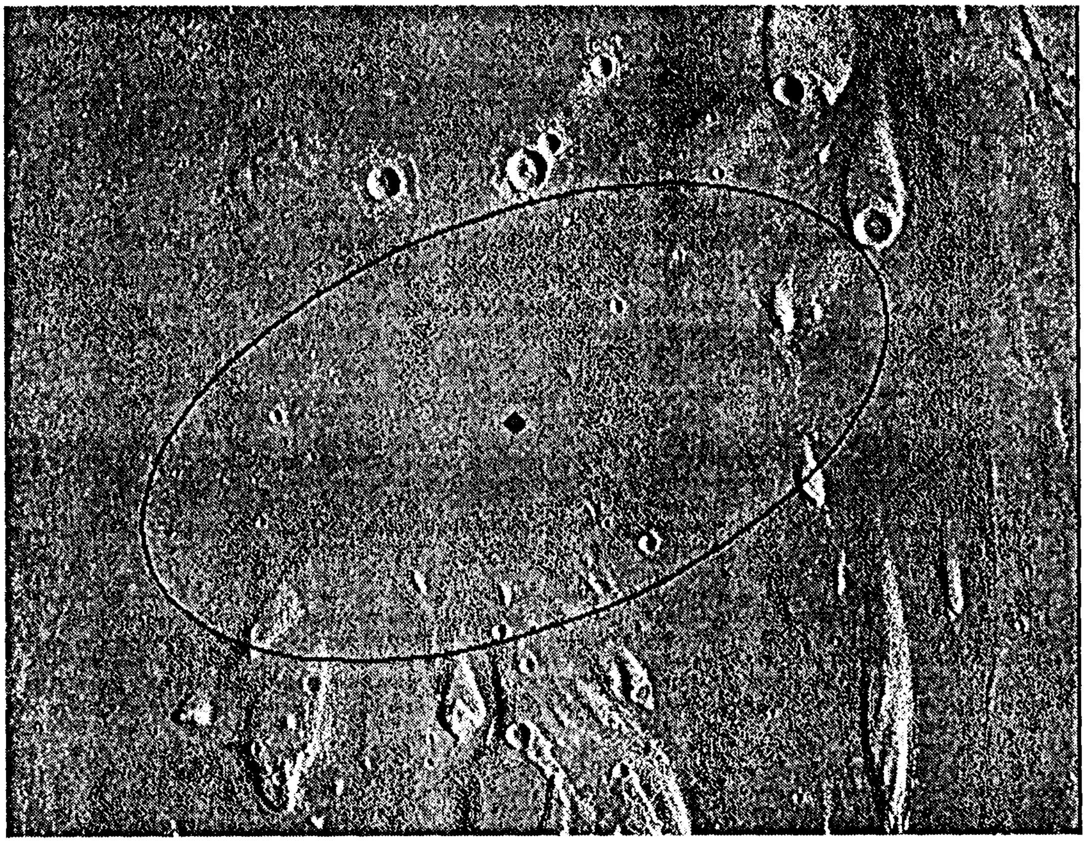

Figure 2: The landing site in Arcs Vallis

## Spacecraft Description

Figure 3 shows the 890 kg spacecraft in its configuration for interplanetary cruise. The lander and rover are enclosed inside an aeroshell (heatshield and a backshell) and a cruise stage is attached to the top of the aeroshell. Inside the backshell is a parachute and three solid rocket motors which are used for the descent phase. The cruise stage contains all the subsystems necessary for power, propulsion and attitude determination and control during interplanetary cruise. A 4.4 $m^2$ gallium arsenide solar array cover the majority of the top part of the cruise stage, providing a minimum of 140 Watts. Attitude determination is performed with a Magellan-heritage star scanner, 3 Sun sensors mounted around the perimeter of the stage and 2 other Sun sensors located near the center of the. top face of the circular plate, inside the launch vehicle adapter ring. The propulsion system consists of four titanium tanks containing hydrazine propellant connected to two clusters of four 4.45 N thrusters via series latch valves and fuel lines. The tanks are loaded with 97 kg of fuel giving a total AV capacity of 125 m/sec for midcourse maneuvers and attitude control. A conical medium-gain antenna is also housed on the top face of the cruise stage.

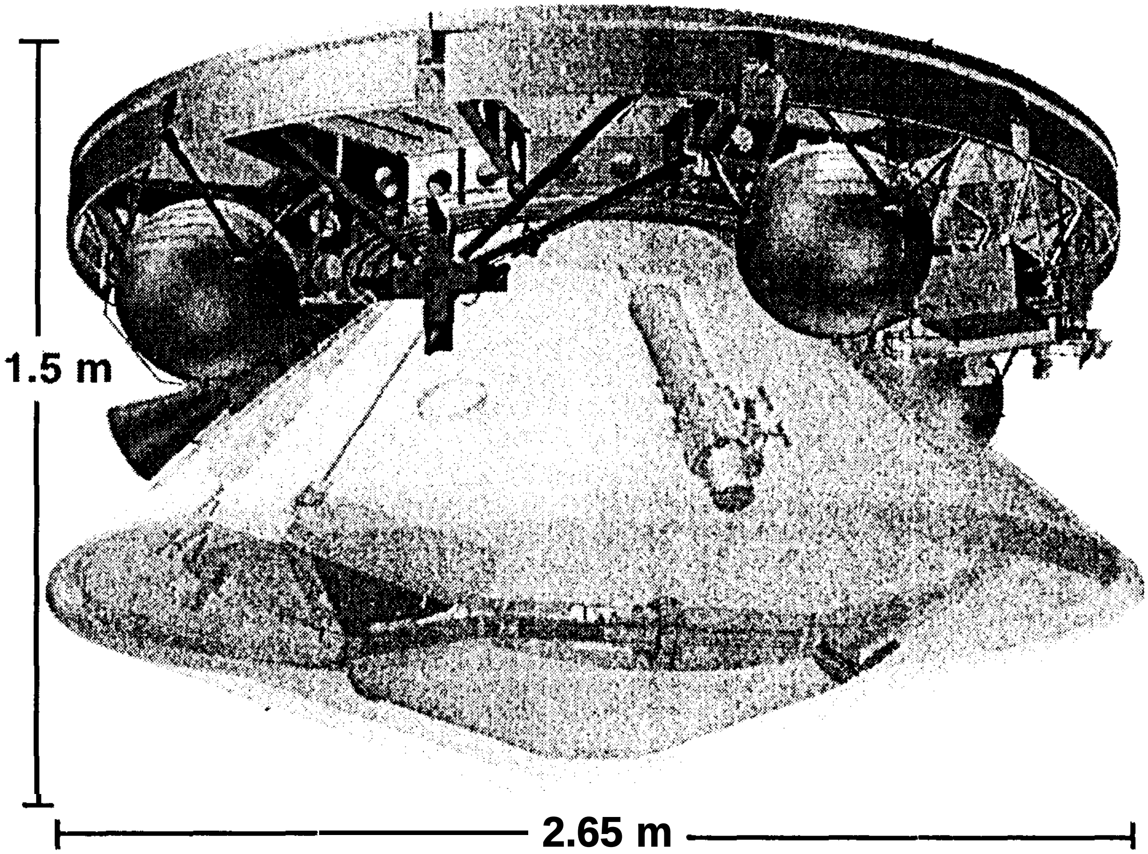


Figure 3: Mars Pathfinder in its cruise configuration

The spacecraft's computer is located on the lander itself and is connect to the cruise stage via a cable harness. The attitude control and data handling functions are handled by an Attitude and Information Management subsystem (AIMS). AIMS uses a high-performance, 32-bit, single-board IBM RAD 6000 computer with 128 Mbytes of dynamic RAM for data storage, plus 4 Mbytes of programmable read-only memory (PROM) for program and critical data storage. An Cassini-designed X-band transponder and Pathfinder-designed solid-state power amplifier are also located on the lander for communication during cruise and surface operation. Other communication hardware include a command detection unit (CDU), a telemetry modulation unit (TMU) and an auxiliary transmitter available as a low-power backup system.

Figure 4 shows the spacecraft as it looks on the surface. The AIMS electronics and the communication hardware are located on the center petal and enclosed in a box-like structure providing thermal protection. Also on the center petal is a high-gain antenna, a low-gain antenna, and the imaging system. The outermost three petals make a three-part solar array of 3.4 $m^2$ total, providing a maximum of 180 Watts for the surface phase of the mission. A rechargeable battery augments the solar array, and is used at night to power the computer and heaters. The microrover, two ramps and a UHF rover communication antenna are attached to one of three petals, while a mast with wind and temperature sensors are located on another petal

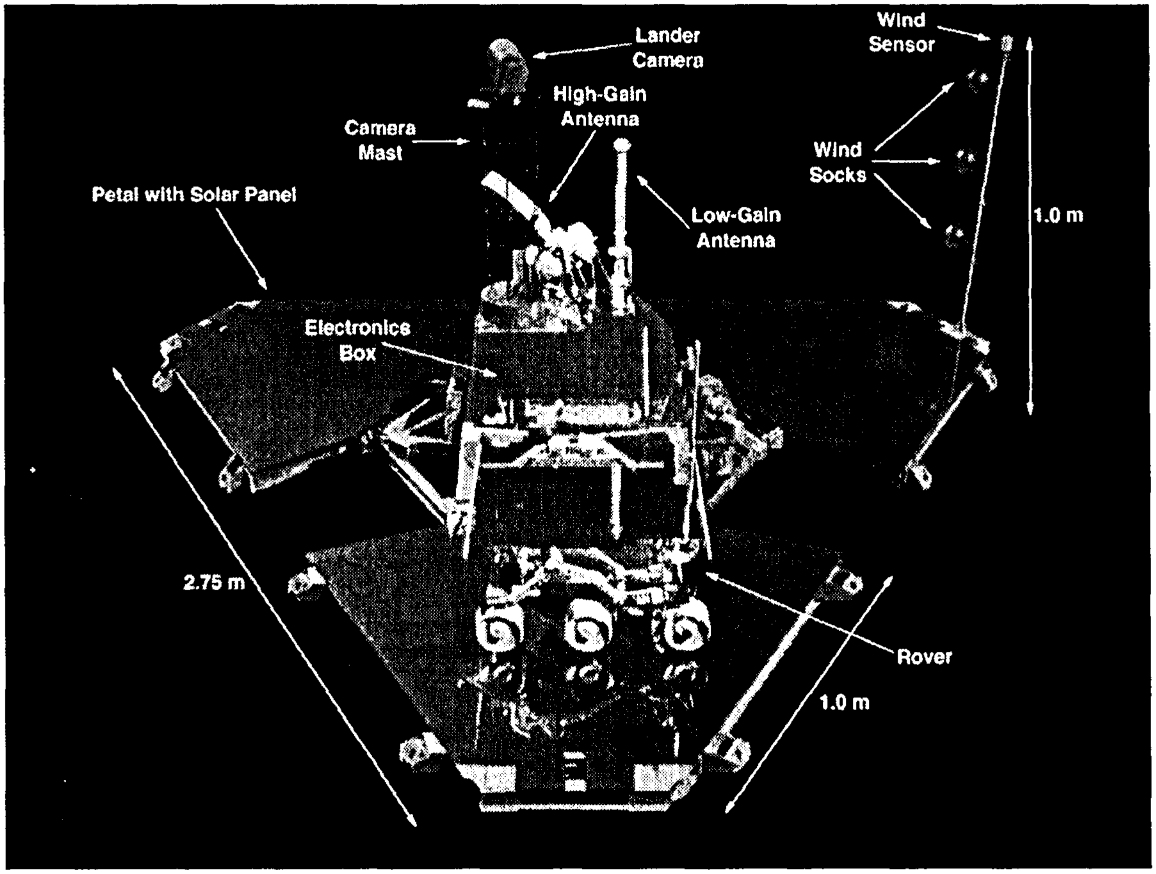


Figure 4: A computer-generated picture of the lander as it appears in the surface configuration

The rover Sojourner rover (Figure 5) uses a six-wheel, rocker-bogie suspension to traverse the Martian surface. It is powered by a 0.22 m2 gallium arsenide solar array mounted atop the suspension system, generating 15 Watts at peak power. Primary batteries supplying 150 W-hours arc carried by the rover for power backup and night operations. The rover has a 0.1 mips 80C85 computer used for autonomous navigation and control of other rover functions. Sensitive equipment is contained in a thermal enclosure called the Warm Electronics Box (WEB). This enclosure is partially heated by operation of the rover electronics during daylight hours and by three radioisotope heater units (RHUs) during the colder nighttime hours. The rover communicates with the lander via an ultra-high frequency (UHF) RF link. A UHF antenna is carried on the rover itself, with a UHF modern and other support structures mounted to the lander. The rover payload consists of fore and aft cameras, an Alpha-Proton X-ray Spectrometer (APXS) and other engineering instrumentation to measure the performance of rover mechanisms.

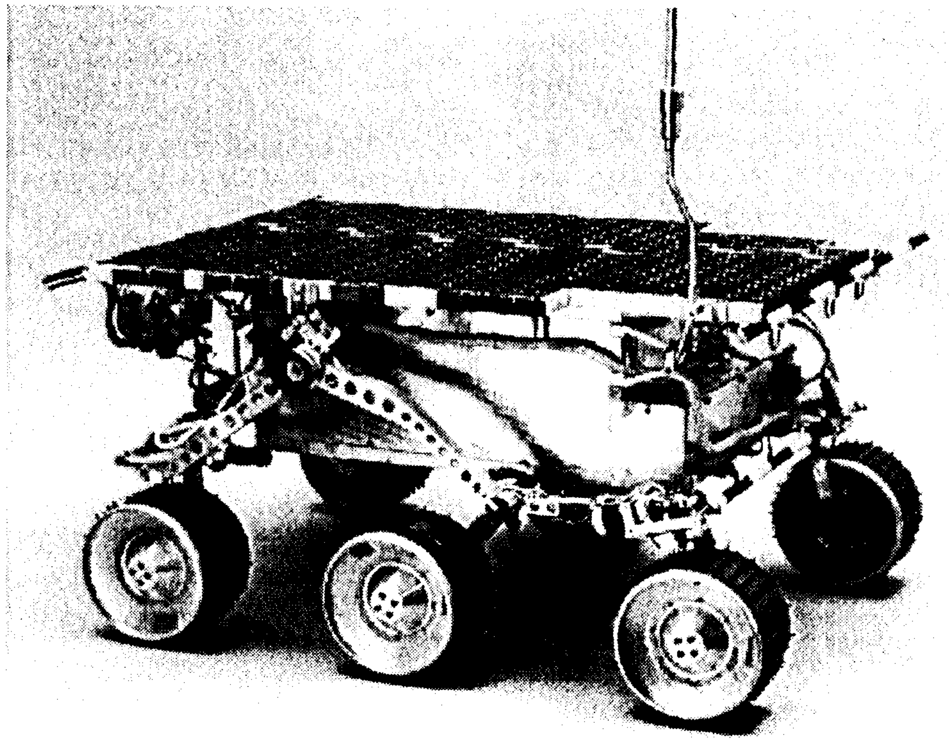

Figure 5: The "Sojourner" Rover

## Mission Chronology

Mars Pathfinder was launched on a McDonnell-Douglas Delta II-7925 launch vehicle on December 4th, 1996 from Cape Canaveral, Florida. Following, a 9.5 minute ascent, the spacecraft and upper stages were placed in a 185 km circular parking orbit. After 57 minutes in orbit, the second stage was fired again, followed by the ignition of the third stage (a Morton-Thiokol Star-48 solid-rocket motor), placing Pathfinder on an interplanetary trajectory to Mars.

Shortly after launch, it was discovered that the two sun sensors heads (number 4 and 5) mounted inside the launch vehicle adapter atop the cruise state were not performing as expected. Later tests on the sensors led the flight team to conclude that the sensor heads were partially obscured, possibly by residue from the launch vehicle separation devices. The remaining three sun sensors on the edge of the cruise stage were not affected, and the onboard attitude determination algorithms were modified to make use of the degraded signal from one of the two affected sensors. Despite these early problems, the spacecraft was able to usc the sensor data to spin down to a rate of 1.9 RPM from its launch spin rate of 20 RPM.

The first trajectory correction maneuver, TCM- 1 was performed on January 10, 1997. The total AV of the correction was 29 m/s, and moved the predicted closest approach at Mars from and altitude of 472,000 to 8140 km, and correcting the time of encounter. The second trajectory correction occurred 25 days later (Feb. 4), requiring only 1.6 m/s to move the predicted altitude to 570 km.

During the 7 month cruise to Mars, the spacecraft was routinely tracked and monitored through the Deep Space Network (DSN). The DSN, with ground stations located in California, Spain and Australia, provides command, telemetry and tracking services for all of NASA's interplanetary missions. Navigation was performed on the ground using a high] y-accurate computer model of the spacecraft's trajectory. Updates to the model were performed by analyzing X-band Doppler and range measurements taken from the DSN during regular communication periods. These measurements were accurate to within 0.1 mm/sec for Doppler and 1-2 meters for range.

A check of the science instruments' health were performed on December 17, 1996. A check of the rover's status was conducted the next day, both checks indicating the science payload had survived launch. Routine monitoring of other subsystems continued throughout cruise. Occasional attitude corrections were needed to maintain the spin-axis of the spacecraft within 5° of Earth and a 40° of the Sun. A total of 17 attitude updates were needed during cruise.

The third midcourse maneuver, a 0.1 m/s correction, was performed on May 7, 1997. As part of the this maneuver sequence, a test of a proposed TCM-5 sequence was performed. This emergency maneuver was one of many developed for use during the final day of approach. There was a 10% possibility of requiring such a maneuver to ensure the lander would touch down within the required landing footprint. A set of 22 possible maneuver sequences were developed and loaded onboard the spacecraft, any one of which could be commanded if needed to make a final course correction.

The fourth course correction was performed nine days before arrival (June 25, 1997), requiring only 0.018 rids. The total required velocity change during cruise was 31.6 m/s, or 1/4 the total capability of the propulsion system.

## Approach, Entry, Descent and Landing

At Entry-2 days, the navigation team predicted a flight path angle of -13.9 degrees at the time of atmosphere entry, which required an update to flight software parameters governing the correct parachute deployment. Subsequent navigation solutions performed over the next 48 hours would show little change in the predicted state at entry. At 10:00 PDT on July 3, the Pathfinder flight team elected to waive off the fifth midcourse maneuver, as the latest navigation solution at that time predicted the lander would touch down only 50 km south and west of the nominal landing site.

The nominal Entry, Descent and Landing (EDL) profile is shown in Figure 6. Entry into the atmosphere of Mars occurred on Jul y 4, 16:51:50 UTC, at an altitude of 125 km. During Entry, the peak deceleration measured by the onboard accelerometers was 16 G's. 170 seconds after entry at an altitude of 8000 m, a 8.3 m parachute was opened at a velocity of 370 m/s, very close to the desired value. The parachute, developed by Pioneer Aerospace, was similar in design to those used for the Viking landers. After the chute was fully deployed, the heatshield was released, the lander was lowered from the backshell on a 20-meter bridle made of Kevlar.

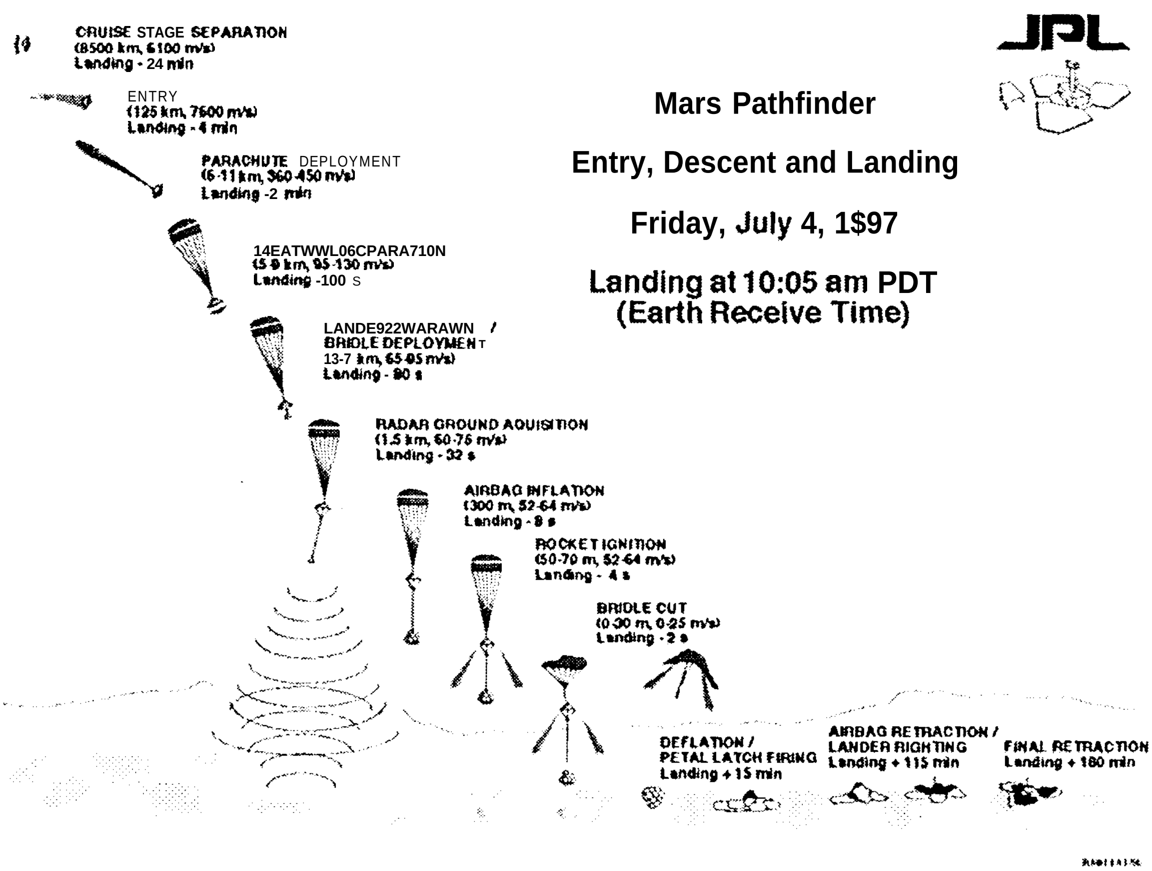


Figure 6: Nominal Entry, Descent and Landing (EDL) sequence of events

A radar altimeter mounted beneath the lander was activated after bridle deployment and began measuring the distance to the surface, providing information on when to inflate the airbags and fire the deceleration rockets. The airbags were inflated 119 seconds after parachute deployment, and the rockets fired 4 seconds later at an estimated altitude of 89.7 m. The bridle was then cut from the lander, leaving the lander to fall 4.2 s the surface, giving an impact force of nearly 15 G's. The lander/airbag combination would continue to bounce for over a minute and a half, finally coming to rest just 3 km from the rim of a crater. All throughout this phase, six accelerometers (3 for science, 3 for engineering) recorded the deceleration profile and dynamic motion of the lander, for later use in reconstruction of the atmosphere density and the entire flight path from atmosphere entry to final stop.

From Earth, the 34-meter and 70-meter antennas in Madrid, Spain were able to track the spacecraft using a wide-spectrum digital signal processor/recorder, providing the flight team with visibility into the events immediately before and during the entry phase. Lock on the signal was lost during the descent but was regained shortly after landing, indicating that the lander had come to a stop with its base plate nearest the. ground and the antenna pointed up. For the next 120? minutes, the airbags were deflated and retracted, and the three side petals were opened.

## Surface Mission

Once the petals had fully deployed, the spacecraft performed its first downlink session from the surface at July 4, 21:07 UTC, relaying back data on the status of the subsystems and critical data collected during entry and descent. The results were excellent; all major subsystems had survived the landing and were okay, including the rover, now rest ing atop one of the three petals. The lander's accelerometers indicated a 2.8° t i It, well within the operational 1 imits. Communicant ion with the high-gain antenna was established later, permitting a data rate of 8520 bits pcr second. The first image relayed to Earth was of the rover petal, showing part of an airbag in the way of the rover ramps (Figure 7). To fix this problem, the lander was commanded to raise the petal 45°, retract the airbags again, and lower the petal back down. Subsequent imaging from the IMP indicated the ramps were clear of airbag obstruction, and the command to extend the romps was issued. A series of images from the IMP of the surrounding area showed an amazing site; a huge variety of rocks of various sizes and shapes scattered throughout the area, exactly what was anticipated from the scientists who selected the site 3 years earlier. In the distance of the images was the rim of a 2-km diameter crater, two small hills and some smal 1 knobs (Figure 8). These distant landmarks would permit the localization of the lander at 19.33 North latitude and 33.55 West longitude, a point less than 27 km from the landing target and well within the 200 km x 100 km requirement shown in figure 2. The final activity before the Earth set below the horizon was to deploy the ASI/MET instrument mast.

The second day of activity on the surface (Sol 2) began with sunrise over the landing site at 17:15 UTC on July 5. The flight team, upon reviewing images of the deployed rover ramps, discovered the left ramp had cantilevered (not touching the ground), but that the right ramp had deployed properly. The rover was commanded to roll down the right ramp and come to a stop 10 cm from the edge, while the lander took images of the rover's descent. On July 6, 05:00 UTC, Sojourner became the first mobile vehicle to roll out onto the surface of another planet (Figure 10). Before the end of the martian day, the rover placed the APXS instrument down onto the soil to began a 10-hour analysis oft he composition of the surface.

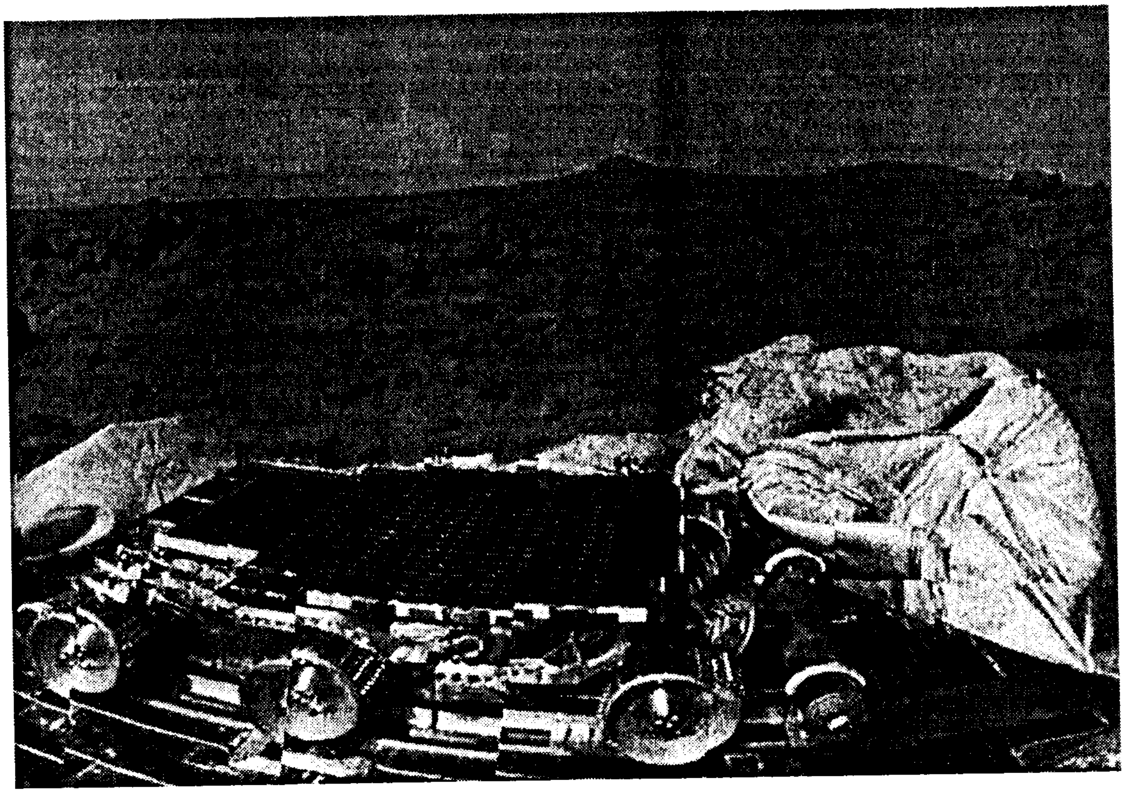

Figure 7: One of the first images taken from the lander.

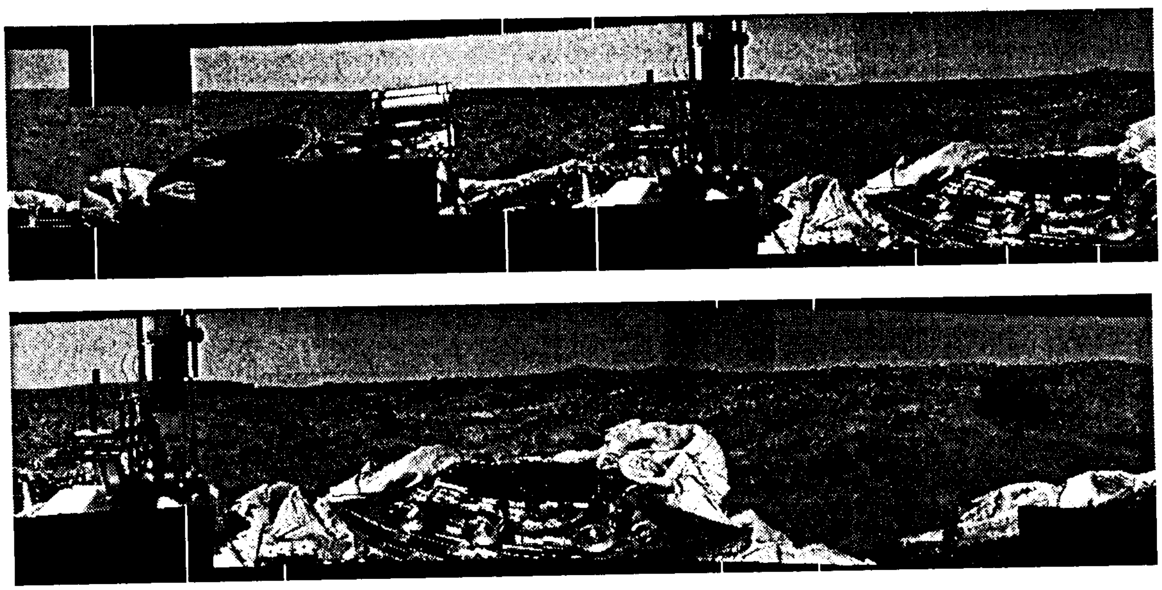

Figure 8: A panorama of the landing site composed of over 200 individual IMP images

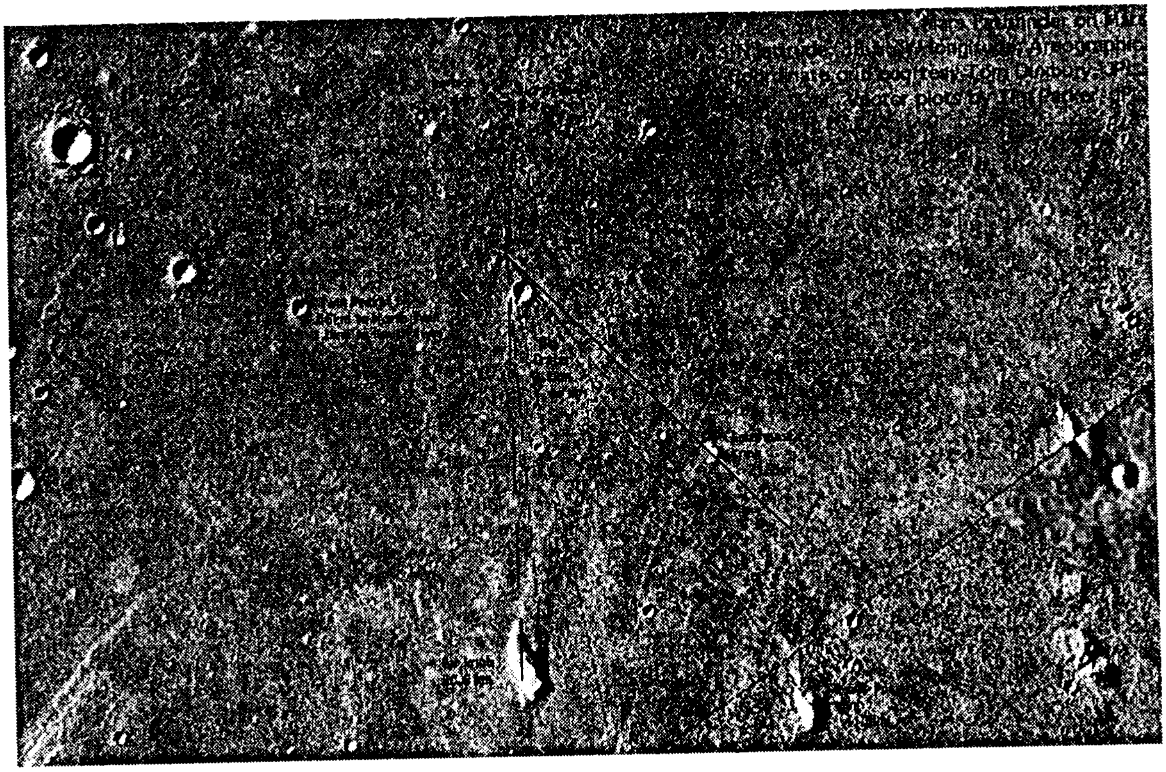

Figure 9: The landing, site as determine by landmark recognition (courtesy Tim Parker)

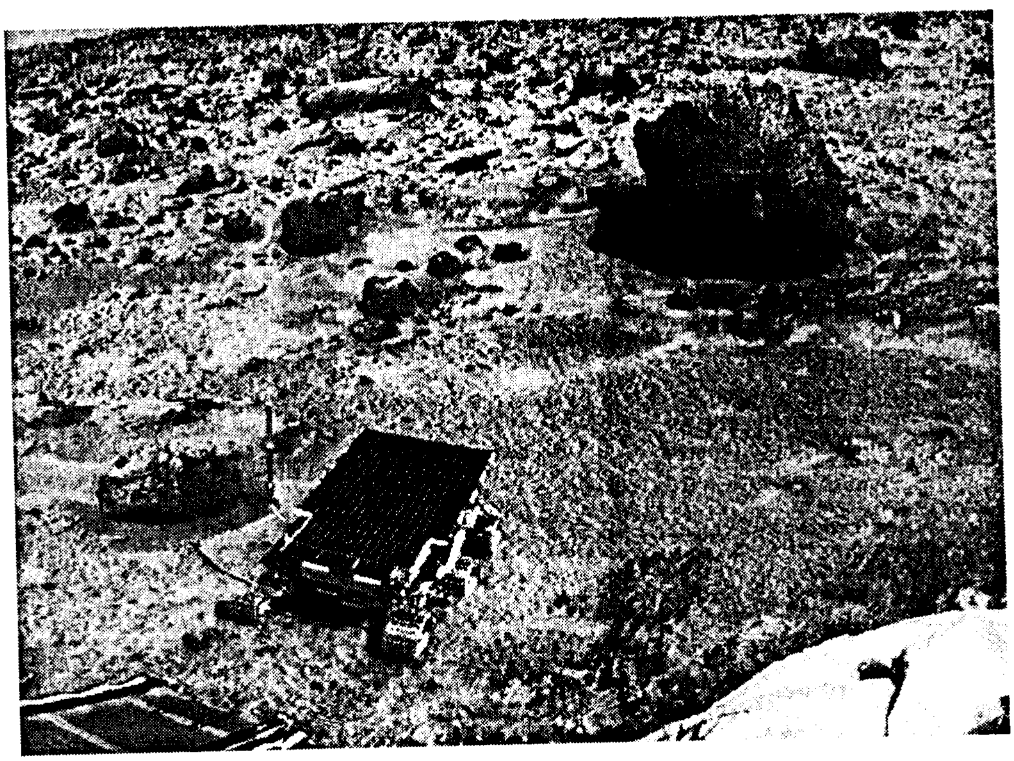

Figure 10: Sojourner deployed on the surface

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## Summary

Mars Pathfinder has been tremendously successful in demonstrating that it is possible to conduct important scientific and technical experiments at a fraction of the cost of previous planetary missions. In Mars Pathfinder's first 48 hours on the surface, it has successfully completed the following engineering objectives:

- Safe landing.
- A panoramic image of the landing site.
- Deployment of the rover into the surface.
- Deployment of the APXS against the soil.

As for the scientific objectives, the instruments onboard these two vehicles have already provided the Pathfinder science team with a wealth of data, with much more to follow in the days ahead. The lander was originally designed to survive for a prime mission of 30 days and the rover designed for a 7-day mission. Yet it is very possible that both will survive beyond their designed lifetimes, providing an extended mission lasting as long as one year.

## Acknowledgments

Special thanks to Peter Smith, Principle investigator for the IMP, who supplied the images used in this paper (Figures 7, 8 and 10), and Tim Parker for figure 9. Additional material was provided by Dr. Robert Anderson and Dr. Sam Thurman.

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