Final draft, for publication

Mars Pathfinder Mission Pioneers New Techniques, Presents Challenges for Test Engineers

Authors: Rick Smith, Manager, Dynamics Department, Wyle Laboratories Inc., El Segundo, CA
Robert Galletly, Technical Manager, Jet Propulsion Laboratories, California Institute of Technology, Pasadena, CA.
Mark Lapin, the Article Works, Santa Clara, CA.

Background and Intent of Pathfinder Mission

Mars Pathfinder, the first mission to land on the surface of the Red Planet since Viking two decades ago, is designed to play a crucial role in NASA's long-term strategy for exploring the Martian environment. Launched aboard a Delta 11 rocket from the Kennedy Space Center in Florida in December 1996, Pathfinder will initiate a series of explorations involving multiple lander and rover missions spaced about two years apart. Orbiters launched in the same time period will carry instruments to serve as relay stations for later international missions. Collectively called the Mars Surveyor Program, this *new* generation of launches aims to explore Mars and provide new information in three areas: evidence of past or present life, climate, and resources (see REF A).

The objectives of the Mars Pathfinder mission fall into three primary categories science, spacecraft engineering, and rover technology. The scientific goals of the mission include studying Martian atmosphere and weather, determining the composition of rocks and the distribution of minerals on the surface, and determining the magnetic component of Martian dust.

Pathfinder will also perform a number of significant spacecraft-engineering experiments. One key objective is to demonstrate a low-cost entry, descent and landing system capable of placing a scientific payload on the surface of Mars (see figure 1). Other engineering objectives include evaluating a highly integrated, high-performance avionics package; using a commercially developed, multitasking, computer operating system; and assessing the performance of solar arrays in the swirling Martian dust.

The Pathfinder mission will carry the first autonomous rover ever to explore the surface of another planet. Mounted on six wheels and powered by a combination of batteries and solar arrays, the micro-rover will demonstrate the usefulness of rover vehicles for deploying and carrying out scientific experiments on Mars. If all goes well, the rover (designed by JPL in Pasadena, California) will be the prototype of a new generation of micro-vehicles destined to expand our knowledge of the Martian surface in the coming decade,

Before the rover can begin to navigate the Martian terrain, it must first survive the rigors of launch from earth and landing on the red planet, The following portions of this article focus on the rover and the acceleration and acoustic tests conducted to ensure that it will arrive on Mars in a fit condition to perform its mission.

The Micro-over Flight Experiment, a.k.a. Sojourner Truth

The vehicle that will land on Mars has a mobile mass of 10.5 kilograms. On top is a flat solar panel a quarter of a square meter in size that will provide 16 watts of peak power. The rover has a primary battery that will provide 300 watt-hours of power. It has a normal height of 315 millimeters (not counting UHF antenna) with a ground clearance of 150 millimeters. It is 630 millimeters long and 480 millimeters wide. Its six wheels are mounted on a rocker-bogie suspension system that permits the rover to climb over small rocks. The wheels **are made of aluminum with steel cleats which will be able to survive even the frigid Martian nights when temperatures plunge to -110 degrees C. Each wheel is powered by a 2. S-Watt motor.**

Officially called the Mars Pathfinder Microrover Flight Experiment, the rover gained a more poetic name as the result of a worldwide, year-long competition. Students up to the age of 18 were invited to submit essays about real-life heroines whose names and accomplishments suited the spirit of the mission, The winning name was Sojourner Truth, after an African-American woman who risked life and limb to" travel up and down the land" during the Civil War era, championing equal rights for all.

During the cruise to Mars, the Sojourner will be mounted on one of the three panels of the Mars Pathfinder Lander. The lander stage provides the rover with structural and thermal support and limited data collection and transmission capability, During the descent to Mars, both rover and lander will be enclosed in a shell that contains a solar array, medium gain antenna, propulsion thrusters, valves and tanks,

Control and guidance of Sojourner on the irregular Martian surface presented a particular challenge. Because of the space-distance-time lag, a message beamed from Earth to Mars takes up to 20 minutes. Sojourner crawls along the surface at a rate of about 3,3 feet per minute, But even at that snail-like speed, it could get into plenty of trouble during the hour or two required for an exchange of several messages,

To get around obstacles, Sojourner will employ a navigation system that combines human and robotic intelligence. The lander carries a camera system which will acquire stereo images of the rover for transmission back to JPL scientists in Pasadena, Using special goggles to transform the images into a 3-D terrain map, the scientists will plot a short course for the rover to follow, If unexpected obstacles appear, Sojourner will attempt to steer around them using an on-board camera and a laser-image-finding system under computer software control. The control scheme was developed at MIT and enhanced at JPL.

Not-so-soft landing

To reduce the cost and complexity of using numerous rocket bursts to cushion the landing, NASA will use an ingenious entry technique that constitutes one of the most important aspects of the Pathfinder mission, The lander will enter the upper atmosphere of Mars traveling at a speed of 7,6 kilometers per second and an angle of 14.2 degrees (90 degrees is straight down). It will reach peak atmospheric shock at less than 20 times Earth gravity at 30 kilometers above the surface, During this time, the payload will be encased in a heat shield designed to partially slow its descent. At ten kilometers above the surface, when the lander is still traveling at approximately twice the speed of sound, a parachute will deploy. The drag of the parachute and a burst from rockets in the backshell will reduce speed to 20m / sec or 45mph. At six kilometers above the ground, the lander will drop down from the backshell at the end of a 20 meter bridle. Moments before impact, four giant airbags will deploy around the lander in a spherical pattern. The bridle is cut and a final burst of rocketry will the carry backshield and parachute away from the landing site. The lander in its sphere of airbags will then bounce down on the Martian surface. Just how high, how far and how many times the package will bounce depends on the particular features of the surface it encounters. It will land in an ancient floodplain called Ares Vallis in Chryse Planitia. But whether the precise point of impact will be a sharp rock or a sandy depression is anybody's guess, Throughout this eventful process, on-board sensors will measure acceleration, airstream pressure and temperatures, The data will be returned in real time during descent. Later analysis will pave the way for refinements of the landing technique and lander design. Once on the surface of the planet, the lander will open its panels and the rover will trundle out to begin its explorations.

Testing the unknown

The use of microvehicles and the low-cost system for soft-landing them on the Martian surface are key elements not only of the Pathfinder mission but of the entire Mars Surveyor Program. Thorough testing was a prerequisite for mission success, But test engineers had to confront some major challenges. Chief among them were the schedule-critical nature of the mission and the many unknowns involved in using anew technique to land a previously untried vehicle ona poorly understood surface,

Since the Delta II is a tried and true launch vehicle, engineers had an accurate picture of the acoustic and acceleration values that the lander (and rover) would encounter during lift off. The landing was entirely another matter. It was difficult to be precise about the acceleration loads the module would encounter during the various phases of its descent to the surface. The actual impact loads would vary drastically depending on the precise angle of impact and the nature of the impact surface.

Test Planning

To account for such variables, it made sense to build an ample margin of error into the test process, Over-testing could result in damage and delays that might doom the whole mission. The Pathfinder had to fly through a very narrow launch window. If lift-off could not take place within a specific ~~two hour~~ four week period, orbital conditions could delay the mission for years. Adding to the schedule difficulties was the fact that engineers from many different disciplines had worked together to create the Sojourner and all of them **wanted to** be physically present during the test.

Acceleration tests

Acceleration and acoustic testing of the Sojourner took place at Wyle Laboratories in El Segundo, California, For acceleration testing, the lab attached the rover to a centrifuge with a ten-foot radius arm and a maximum load capability of 600 g, The indoor **centrifuge** and **support facility had a long history in space-oriented testing, but both had** been recently upgraded to accommodate newer payloads. Fixturing was a matter of particular concern, JPL set very strict standards for fasteners and bolts to prevent damage to the vehicle or danger to test personnel. Another challenge involved the fact that the rover **was not** built to withstand severe aerodynamic disturbance since it would be shielded from winds during both launch and descent, Centrifuge testing, however, would expose the vehicle to severe winds, JPL and Wyle engineers decided to enclose the vehicle in an airtight shield during centrifuge testing.

A further obstacle involved data collection. A test-object whirling around at the end of a 10-foot centrifuge arm presents considerable challenges. The Wyle facility was equipped with 121 slip-ring charnels which fed data from numerous points on the specimen to a centralized control room (where the large group of observers watched the proceedings through viewports). The first round of acceleration tests reached a maximum of66 g's (significantly higher than the maximum load). Early tests revealed a performance anomaly on one of the rover's wheels, After redesign, the wheel passed subsequent tests.

Acoustic Tests

Although protected from aerodynamic disturbance during launch, the rover would be exposed to a harsh acoustic environment. For acoustic testing, engineers at Wyle had to simulate this acoustic environment while maintaining JPL's strict standards for cleanliness and safety. Acoustic testing took place in high-intensity reverberation chamber with a clean-room environment, The chamber had frequently been used for testing satellite components. During the tests, the rover was suspended by bungees cord from the ceiling of the acoustic reverberation chamber. It was subjected to sound pressure levels exceeding 139dB for a duration of 60 seconds,

For accomplishing the test program within the tight schedule, Wyle personnel received an unusual form of recognition. JPL scanned the signatures of the people involved and engraved them on a microchip, That chip, attached to the base of the lander, is now on its way to a permanent new home on Mars.

#####

McCleese

REF A: Donna L. Shirley and Daniel J. Melrose, "Mars Exploration Program Strategy: 1995 -2020," AIAA 96-0333, 34th Aerospace Science Meeting, January 15-18, Reno, Nevada.