An Overview of Dynamics Testing of *Mars Pathfinder* for the Martian Landing Environment

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Mars Pathfinder—which successfully landed on Mars on July 4, 1997—was part of the Discovery Program, a National Aeronautics and Space Administration (NASA) initiative for a new class of smaller missions utilizing the "faster, better, cheaper" approach to planetary exploration. Its principal mission objective was to demonstrate a simple, reliable, and lowcost system for placing a scientific payload on the surface of Mars. The successful landing enabled deployment of the well publicized *Sojourner* Mars Rover, and returned scientific data in amounts greatly exceeding the original mission objectives.

Pathfinder used an airbag system to safely deliver the lander to the Martian surface. As shown in Fig. 1, *Pathfinder* used a complex entry, descent, and landing sequence involving a combination of atmospheric drag, a parachute, and retrorockets to stop the Lander's descent approximately 12 meters above the Martian surface. In the terminal phase of this sequence, four airbags were deployed, one attached to each face of the tetrahedral Lander. A gas generator subsequently inflated the airbags, which were designed to mitigate the inertial impact forces associated with the lander's subsequent free fall.

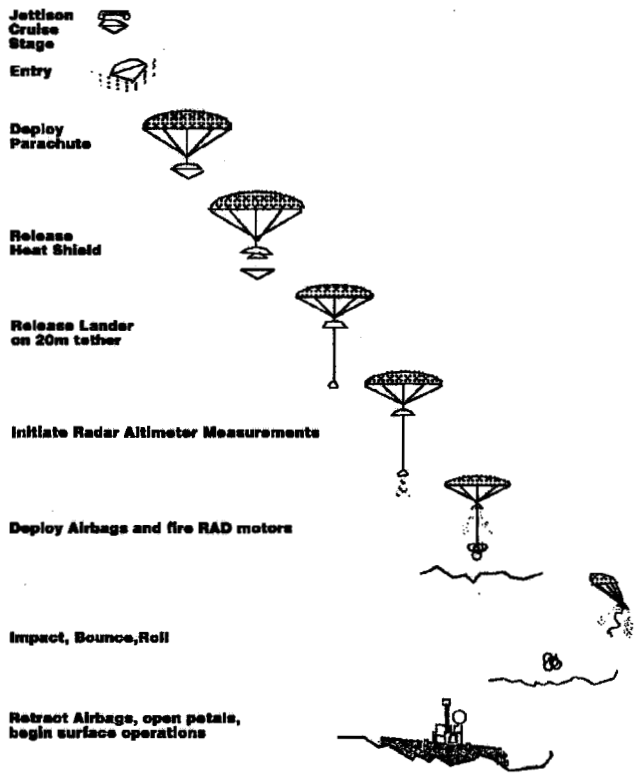

Figure 1 - Pathfinder Entry Descent Landing Sequence

The use of an airbag landing system presented interesting challenges for the *Pathfinder* spacecraft dynamics test program. Besides the traditional series of vibration, acoustic, and pyroshock tests used to qualify hardware for the launch environment, a supplemental series of dynamics tests was required to qualify *Pathfinder* equipment for the airbag landing environment on Mars. The groundwork for this supplemental test program began in 1993 when the Jet Propulsion Laboratory (JPL) and Sandia National Laboratory began a collaboration to design, fabricate, and test a scale model airbag landing system as a proof-of-concept demonstration for *Pathfinder*. Over the subsequent two years, a series of cooperative tests successfully demonstrated the feasibility of using an airbag landing system for a planetary lander.

Buoyed by this success, JPL began a much more extensive series of drop tests on full-scale prototype airbag systems in collaboration with ILC Dover Inc. beginning in April 1995. This series of tests had the following objectives for an airbag landing system operating under Martian ambient conditions:

- to measure lander accelerations, airbag tendon forces, and airbag pressures and temperatures
- to assess the airbag bladder design and fabric abrasion resistance properties
- to determine the frequency and magnitude of the landing excitation
- to use these prototype test results to direct subsequent design modifications

This prototype testing took place at NASA Glenn Research Center's Plum Brook Station in the Space Power Facility (SPF), the world's largest space environmental test chamber. The test configuration consisted of the prototype airbag system attached in flight-like fashion to a full scale engineering unit lander. To characterize airbag performance, the airbags were instrumented with thermocouples and pressure transducers to measure their thermodynamic performance parameters; additionally, for the initial drop series, the tendons connecting one of the airbags to the lander were instrumented with strain gages to measure the inline tendon forces. To characterize the landing dynamic environment, the lander was instrumented with accelerometers to record its kinematic motion; in turn, all of this data was recorded on a portable data acquisition system mounted inside the moving lander. The combined airbag/lander assembly was suspended from the top of the SPF chamber and impacted onto either a horizontal surface or a platform inclined at 60° with a simulated rock field. The drop test setup with the inclined platform is depicted Figure 2. For the initial drops, the airbag/lander system free-fell vertically to a horizontal surface without the simulated rock field. For all subsequent drops, the airbag/lander system was impacted vertically onto the inclined platform with the rock field. The 60° inclined platform simulates the design landing condition of 30° with respect to the Martian surface, and the rock field simulates the best estimate of the actual Martian surface rock distribution based on Viking lander data. To compensate for the loss of drop height caused by the platform, higher velocity impacts were assisted by bungee cords tied to the bottom of the lander. All drops took place at pressures of approximately 5 torr, Martian surface ambient conditions.

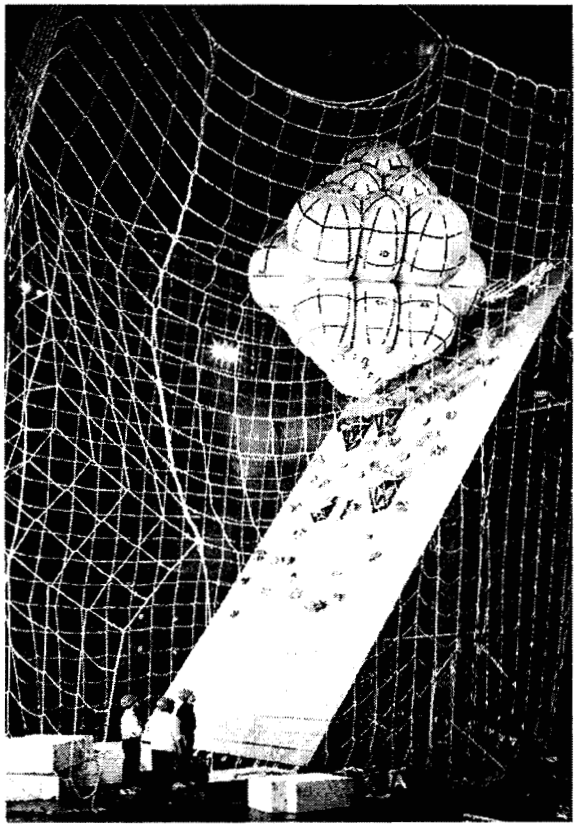

Figure 2 - Drop Test Setup

The extensive data set realized from the nearly 20 prototype drop tests of *Mars Pathfinder* were invaluable in the development and evaluation of the airbag landing system. The force, pressure, and temperature data characterized the performance of the airbags and its tendon attachments; and were used to aid in subsequent modifications to the airbag's design. The acceleration data characterized the landing excitation and were used to determine the appropriate test program to qualify the lander for the Martian dynamic landing environment.

The accelerometer data characterized the landing excitation as a high g, low frequency event. More specifically, the acceleration time histories from the lander base petal were used to conservatively bound the resultant of the lander translational and rotational accelerations at approximately 40 g. The frequency content of the landing excitation was subsequently determined from Fourier transforms of these time histories, and was found to have its predominant energy lobe at frequencies below 10 Hz. Since the frequency of the landing excitation was found to be considerably below the fundamental frequencies of the lander hardware and structure, the lander could be tested quasi-statically. Consequently, *Pathfinder* lander equipment was centrifuge tested at approximately 40 g to qualify it for the Martian landing environment.

Acknowledgments

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