Getting the Rover to Mars in Working Order

Terry Fisher, Jet Propulsion Laboratory, Pasadena, California
Dave Galyardt, LDS-Dactron, Freemont, California

The engineers at NASA's Jet Propulsion Laboratory (JPL) had a problem. They needed to test the next generation Mars Rover in a critically short cycle in order to prove out the new design and not miss their launch window, which could result in delays to the entire Mars exploration program. They also needed a major update to their test facilities while keeping testing on schedule. The failure of one of their older shaker systems caused severe damage to an earlier spacecraft during testing and precipitated the motivation for updating the lab.

When reconstructing the events that caused the failure, it was found that a bearing in the 40+ year-old shaker had failed causing it to go out of alignment. This damage, not outwardly apparent, caused binding and eventual over-test of the spacecraft. As can be imagined, the other project engineers were understandably hesitant to entrust their project's success to questionable test equipment.

Another issue with the old shaker table was that it did not have the multiple hydrostatic bearing capabilities that are available with newer shaker tables. A spacecraft mounted on a shaker table typically has a high center of gravity that causes overturning moments. Multiple hydrostatic bearings provide much better restraint of overturning moments and prevent "oil canning" motion.

With a number of tests scheduled to be performed on the vibration system, the appropriation for the lab upgrade was accelerated to prevent any interruption in the Mars Rover dynamic test program. After reprioritizing the lab budget and acquiring the necessary funding, JPL initiated an open solicitation to companies that offered to upgrade their environmental testing laboratory to reflect current requirements. These requirements included a larger vibration test system that will remain viable for use in shock and vibration testing of spacecraft designs planned for the next ten years. A further key requirement was the ability to deliver the improvements and new equipment on a tight schedule.

After an intensive evaluation, JPL selected Ling Dynamic Systems (LDS) to perform the lab upgrade and install a LDS V994 Vibration Test System. LDS engineers worked closely with JPL to assess existing equipment and systems currently in place and to develop a plan for which equipment would be replaced or rebuilt. From years of testing, the lab had become a mismatch of various suppliers' equipment acquired through partial systems upgrades and retrofits. Disconnected cables from previous upgrades filled trenches and unused older ancillary systems sat blocked in by newer equipment. An action plan was developed to be executed in two phases that would minimize scheduled downtime for the lab.

The three-month schedule for phase one involved complete shutdown of the lab. This phase allowed all the old equipment, control consoles and miscellaneous equipment to be removed. Next came the installation of two new 210 kW power amplifiers, switch network, two LDS V964 20,000 lbf shaker systems with slip tables and new control consoles. An existing 20,000 lbf shaker was reconditioned on site. At the completion of phase one, the lab was partially reopened.

Phase two consisted of the delivery and installation of a 65,000 lbf LDS V994 with an integral 98 in. × 118 in. slip-table with 20 hydrostatic bearings (see Figures 1-2). This system represents one of the largest single shaker systems in the world and provides JPL engineers with testing capabilities for large structures that were previously unavailable.

The entire on-site project was completed within the allotted six month period. After all systems were fully tested and certified for testing of flight hardware, the lab reopened. According to one JPL test engineer, "LDS performed extremely well and delivered the system on time." There were other manufacturers considered to provide this system to JPL but ultimately there was only one supplier that provided all facets of the lab requirements. Substantial construction was required in order to position and support the vibration test equipment, which included laying a 1,000,000 lb seismic mass for the base of the large shaker table. JPL used the down time in the lab to perform many facility upgrades. As the lab structure was very old, several building code upgrades needed to be addressed.

Completion of the lab allowed JPL to perform the required dynamic test program for the new Mars Rover spacecraft in December of 2002 (see Figures 3-4). The new Rover is three to four times the size of the rover that landed on the Martian surface in the late 90s to investigate the atmosphere and potential for life on Mars. The test program sought to verify the worthiness of the new Rover to withstand stresses due to the launch phase and the shock events associated with the landing deployment on Mars. An added objective was to perform a modal survey to provide data to verify the accuracy of the finite element model of the Rover.

Figure 1. The LDS V994 Shaker being positioned in the JPL Dynamics Test Laboratory.

Figure 2. Slip table assembly for V994 Shaker showing additional lateral restraint assembly.

Simulations of launch vibration used random excitation with acceleration up to 20 g in the vertical axis. Half-sine shock pulse excitation provided an assessment of the stresses expected when the rover landed on Mars. Results from the shock and vibration tests indicated a need for minor design changes to the Rover. Tests revealed that the electrical switch for the two-way X-band RFS telecommunications system toggled ITS position due to vibration. A redesign of the switch to withstand higher acceleration levels resolved this issue. Data from the modal survey allowed fine-tuning of the finite element model to accurately predict the structural dynamic responses of the Rover.

Successful shock and vibration testing of the Rover design was a critical step in the preparation for the launch of the two new Rovers in June and July of 2003. As this issue goes to press, the first Rover had landed successfully and transmitted the most detailed images ever seen of Mars' surface. The second Rover was on schedule to land presently.

In addition to the successful Rover test program, the new vibration test capabilities give the test engineers at JPL the equipment needed to evaluate all of the types of spacecraft currently designed. These new test capabilities also ensure that test requirements for launch and

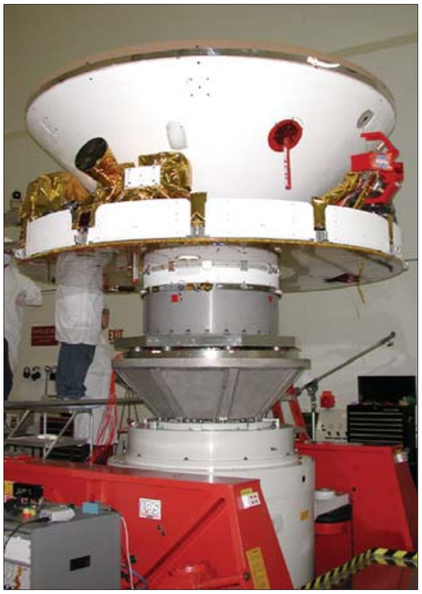

Figure 3. One of two Mars Exploration Rovers sits inside its Cruise stage waiting to undergo vibration testing at NASA'S Jet Propulsion Laboratory. The LDS V994 is the largest shaker system in the world and can produce 65,000 lbs peak force.

Figure 4. The Mars Rover mounted on the slip table for the LDS V994 Shaker. The multiple hydrostatic bearings restrained overturning moments associated with the lateral vibration of the Rover.

operational performance are being met, and will continue to be met in the future. The upgraded JPL lab, with the new shaker tables installed, will provide the data to the design engineers and scientists to better understand the types of stresses confronted by the exploration spacecraft and help them to design for future missions.

For more information on the Mars Rover and JPL Dynamics Test Laboratory visit www.jpl.nasa.gov. Visit www.lds-group.com for additional information on the LDS V994 Shaker System.