Intense Testing Paved Phoenix Road to Mars

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Two participants help test the radar system for NASA's Phoenix Mars Lander. Image credit: NASA/JPL-Calech

When NASA's Phoenix Mars Lander descends to the surface of the Red Planet on May 25, few will be watching as closely as the men and women who have spent years planning, analyzing and conducting tests to prepare for the dramatic and nerve-wracking event known as EDL - Entry, Descent and Landing. For after all their hard work, they know that landing on Mars is not a walk in the park. Less than 50 percent of all previous lander missions have made it safely to the surface.

Like all missions, Phoenix was motivated by the potential science rewards. With its robotic arm, Phoenix will be the first mission to reach out and touch water ice in Mars' north polar region. The mission will study the history of the water in the ice, monitor weather of the polar region, and investigate whether the subsurface environment in the far-

northern plains of Mars has ever been favorable for sustaining microbial life.

Much of the Phoenix spacecraft already sat in secure storage when, in 2003, NASA selected it over other proposals to fly to Mars. Phoenix's main systems were designed and built for launch as the Mars Surveyor 2001 Lander, but that mission was canceled in February 2000, after the loss of a similar spacecraft, the Mars Polar Lander, during its arrival at Mars in 1999.

The team that proposed the Phoenix mission, led by Peter Smith of the University of Arizona, Tucson, developed a plan to bring the spacecraft out of storage, thoroughly analyze and test it, resolve all known problems, and add upgrades so it could pursue a new set of science goals. The spacecraft heritage of the 2001 lander, derived from the "faster, better, cheaper" era, brought with it opportunities, along with several challenges.

Phoenix Project Manager Barry Goldstein of NASA's Jet Propulsion Laboratory, Pasadena, Calif., discussed the team's approach to adapting a pre-built spacecraft for this mission, instead of developing one from scratch: "One consequence of having so much of the hardware in place from the start was that we could focus our resources into testing and analysis. We evaluated the robustness of the vehicle to perform the mission we designed, most notably the entry, descent and landing."

The team first focused on correcting all the vulnerabilities identified by earlier investigations into the loss of the Mars Polar Lander. "That wasn't enough," Goldstein said. "We eventually identified and mitigated more than a dozen other potential issues with the spacecraft that could have had dire consequences." Extensive testing and analysis also identified concerns that could have affected the lander, solar array deployment, and its science instruments after arrival on the Martian surface. However, an

acceptable amount of risk still exists--for example, most hardware is at least 8 to 10 years old, and certain subsystems have no redundancy during the entry, descent and landing.

Goldstein said, "We've done everything we can to lower the risks of this mission to acceptable levels, but in no way does that mean we've eliminated all risk. Planetary exploration is risky by its very nature, and there are numerous challenges ahead of us, the first of which is entry, descent and landing."

Here are descriptions of five examples of problematic hardware and resolutions resulting from the extensive work done by the Phoenix engineering and science team.

Radar

Phoenix uses a radar system initially designed as an altimeter for fighter jets. During the final minutes before landing, after the spacecraft has jettisoned its heat shield, Phoenix will rely on the radar for information about not just the altitude, but also the descent velocity and the horizontal velocity. The onboard computer will use that information several times per second to adjust the firing of 12 descent thrusters.

Using the radar for this novel purpose required a tremendous amount of testing, "We did more than 60 hours of flight testing, including 72 different drops at three sites with different geological characteristics," said David Skulsky, a JPL engineer on the Phoenix team. That's more radar flight testing than all previous NASA Mars missions combined."

Radar tests also included custom-developed simulations of performance under Martian conditions. Running one of those simulator tests just four months before the spacecraft was due to be delivered to Florida for launch, Curtis Chen, a JPL radar engineer, noticed some strange

behavior. Analysis confirmed that, under some circumstances, the radar could be confused by the jettisoned heat shield.

JPL's Dara Sabahi, chief engineer for Phoenix, said, "If this occurred in flight, the spacecraft would think it was much closer to the ground than it actually was. It would be a guaranteed failure."

Once the testing had revealed the potential problem, engineers designed a relatively simple solution using adjustments related to the timing of radar pulses. However, the schedule was tight, and additional flight tests were needed to be sure that fixing that issue had not created others. "We worked all the way to launch on the testing, and even did more testing after launch to be sure we understand the performance," Sabahi said.

In addition, NASA formed a Radar Independent Review Team of key radar experts to evaluate the activities of the Phoenix team working with the radar. The review team was chartered to determine if the radar had been properly characterized, if the important risks associated with its performance have been identified, mitigated, and that unmitigated residual radar risks represented a low risk to the mission. The Phoenix team followed all recommendations from the Independent Review Team. The review team endorsed the approach taken by the project to resolve all anomalies. They concluded that the probability for a successful landing on Mars under radar guidance was comparable to or better than that of prior missions.

Parachute

The lander will separate from its parachute about 40 seconds before reaching the ground. Thrusters will begin firing half a second later and continue pulsing all the way to the surface, controlling both vertical and horizontal velocity, plus the spacecraft's orientation.

"We did some analysis that showed there was a three-to-five percent chance, depending on wind conditions, that the lander would have some kind of re-contact with the parachute," said Rob Grover, chief of the Phoenix entry, descent and landing team at JPL. "The worst situation would be to have the parachute come down right on top of the lander and prevent deployment of the solar arrays."

Rather than rely on the odds against such an occurrence, engineers designed a maneuver for the lander to avoid the parachute. Horizontal motion identified by the radar while the lander is still connected to the parachute will indicate wind direction and speed. If the wind is strong, the parachute will blow away on its own. If the wind is weak, the lander will use its thrusters after separating from the parachute to push itself upwind, away from the falling parachute.

Motors

The robotic arm on Phoenix uses four electric motors from the same lot of 211 motors originally purchased for NASA's Mars Exploration Rover project. Fifty of the motors were sent to Mars on rovers Spirit and Opportunity. Of the remaining motors, later testing identified two whose brushes were broken. Motor brushes provide electrical contact between moving and stationary parts of the motor. The brushes in these motors are solid pieces of a special mixture of copper, graphite and molybdenum made for Martian conditions.

The motors installed on the Phoenix spacecraft had been tested and showed no trouble. In addition, their counterparts on Spirit and Opportunity have far outperformed their design life under stressful real-Mars conditions. For the Phoenix team, the issue was how to assess whether the two broken brushes were enough reason not to rely on the motors in the robotic arm. Goldstein, the Phoenix project manager, said, "We did not rest on these motors' excellent track record with Spirit and

Opportunity. We did our own testing."

The Phoenix project put the arm motors through additional testing and also turned to the NASA Engineering and Safety Center, a resource created for providing just such assistance with independent analysis of engineering issues related to risk for NASA projects. The Phoenix team followed recommendations from a review team formed by the center. These recommendations included using sensors to monitor any jarring of the motors during transportation of Phoenix from Denver, where it was built by Lockheed Martin Space Systems, to Florida for launch.

Scoop

Central to the design of the Phoenix mission is the intent to dig to an icy layer under the surface and deliver some of the ice-rich soil to a small laboratory on the deck of the lander. That icy soil will probably be as hard as concrete.

The original design for the scoop at the end of the arm had three sets of metal blades for cutting and scraping to loosen enough icy soil to sample. The Phoenix team ran tests using sample materials as tough as those expected on Mars.

JPL engineer Lori Shiraishi said, "We found it took four to six hours to get enough material, but you are also fighting sublimation of the ice. The ice would be disappearing by the time you are trying to pick it up."

In 2005, the team began working on an alternative design to loosen and collect an icy sample more quickly. JPL's Gregory Peters came up with the idea of a motorized rasp to replace one of the sets of blades. Honeybee Robotics Spacecraft Mechanisms Corp., New York, built and tested the redesigned scoop. The rasp uses a tile-cutting bit lowered at an angle through a slot in the bottom of the scoop. Tests indicate the system

can loosen and lift and deliver an icy sample in about half an hour, which is believed to be quick enough to outrun sublimation of the exposed ice under Martian atmospheric conditions.

Stowaway carbon

The Phoenix team has tested all of the lander's science instruments extensively. One that sniffs vapors generated from heating samples of soil and ice will be checking for organic molecules. Most carbon-containing chemicals are called organics. Organic chemicals can be present without life, but they are an essential ingredient for life as we know it. Testing made clear that this instrument -- the Thermal and Evolved-Gas Analyzer -- is sensitive enough to detect the trace amounts of organics that are likely to come from Earth aboard the lander.

"We want to be able to determine whether we're just seeing organics we brought along with us," said William Boynton of the University of Arizona, Tucson, lead scientist for this instrument.

The university assembled a meeting of organic chemists from around the country in 2005 for a discussion of how to prepare for analyzing the data from Phoenix. From that workshop came a recommendation for Phoenix to carry "blank" material specially made to be as free of carbon as possible, for use as an experimental control for comparison with samples of Martian soil and ice.

The Phoenix team assessed various possibilities for the blank material. The lander is carrying a block of a custom-made, very-low-carbon ceramic product from Corning Inc. During operations at the landing site, the powered rasp will be able to produce shavings from the blank for analysis. The results will help scientists interpret whether any organics found during analysis of Martian samples actually came from those samples.

There are many other examples of how the Phoenix mission has identified concerns through testing and analysis, and then resolved them.

Goldstein said, "I can't guarantee success. We are in the business of taking risks, doing things that are very difficult. However, I am confident that we have a world-class team that has dug as deep as it could to find any problems."

Source: NASA

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