9 AEROSPACE AMERICA OCTOBER 2009

October 2009

AEROSPACE AMERICA

Mars laboratory lands on red ink

Space debris: A growing challenge

A conversation with Graham Love

A PUBLICATION OF THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

Mars laboratory lands on red ink

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In NASA's catalog of planned robotic Mars missions, the largest and most complex is a proposal to land on the Martian surface a mobile spacecraft roughly the size of a school bus. The Mars Science Laboratory (MSL), conceived by NASA engineers and weighing in at over 2,000 lb, is the most ambitious Mars mission ever planned. The lander, weighing 10 times more than previous Mars rovers, will carry to the planet the most advanced collection of scientific equipment ever brought there.

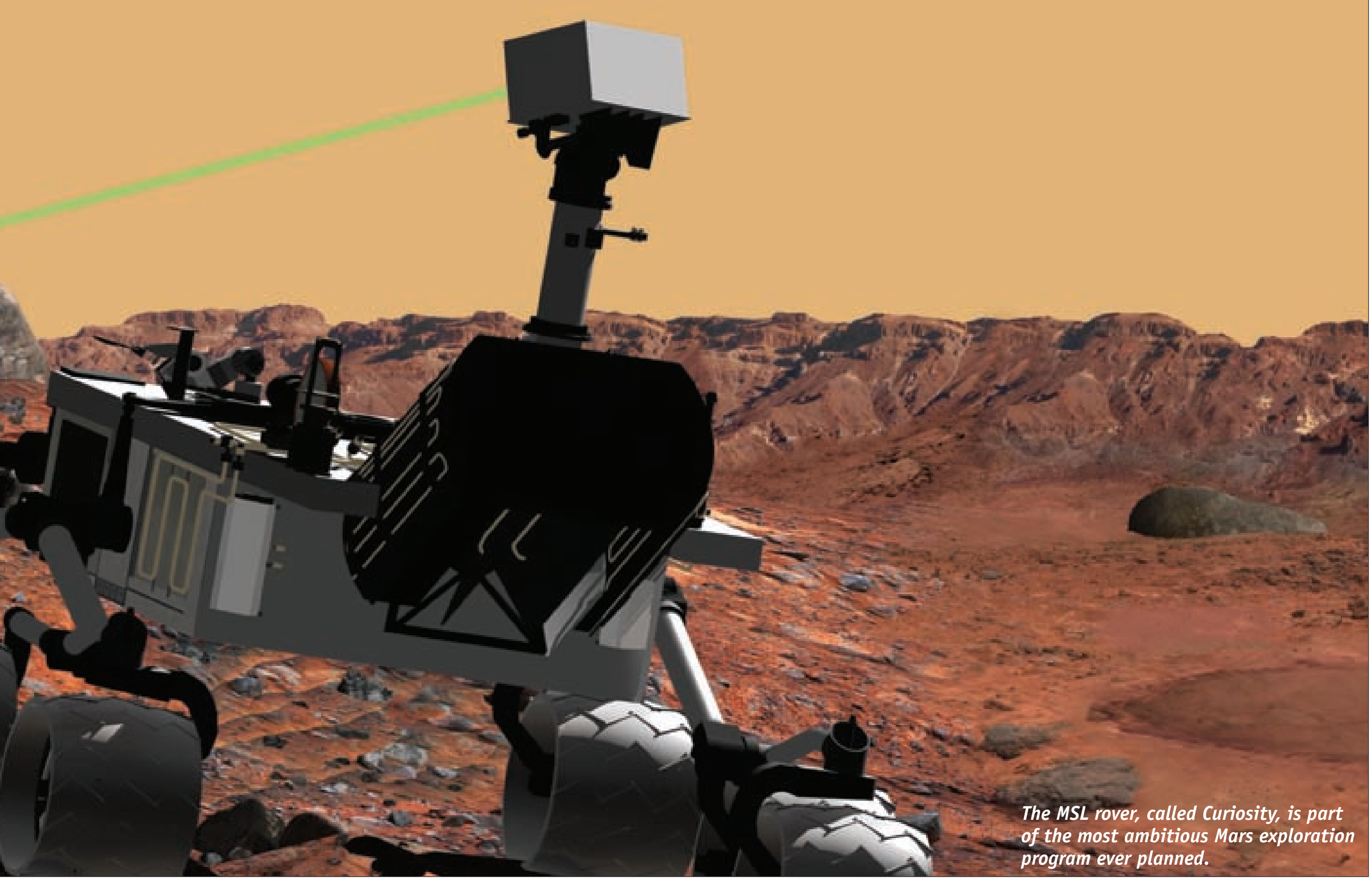
MSL's primary mission is to evaluate the planet's ability, past or present, to sustain life. And unlike the previous robotic Mars missions, this one will steer itself through the Martian atmosphere in a space-shuttle-like descent trajectory, then use a combination of rocket propulsion, parachutes, and crane-like hoists to drop the rover onto a carefully preplanned, narrowly defined landing site.

But in the face of such challenging goals, technical problems and budgetary pressures have led to a flight delay and have even threatened the viability of the project itself. Indeed, MSL has become a test case for placing management constraints and budget boundaries on even a favored project.

Setting the research goals

From the outset, NASA established four goals for all Mars missions: Determine if life ever existed on Mars, define the planet's climate, compile data on its geology, and establish data about Mars that could be used in future human visits.

Eight scientific research goals were also set. Three are biological: Determine the nature and inventory of organic carbon compounds; inventory the chemical building blocks of life (carbon, hydrogen, nitrogen, oxygen, phosphorous, and sulfur); and identify features that may represent the effects of biological processes. Two goals are geological and geochemical: Investigate the chemical, isotopic, and mineralogical composition of the surface and near-surface geological materials; and interpret the processes that formed and modified rocks and soils. Two others are planetary process goals: Assess long-timescale (4-



The MSL rover, called Curiosity, is part of the most ambitious Mars exploration program ever planned.

NASA's MSL, the most ambitious Mars mission yet planned, has faced major challenges, both technical and budgetary. With the current launch window fast closing and important issues still unresolved, the agency has taken decisive action and unusual steps to safeguard the troubled program.

billion-year) atmospheric evolution processes; and determine the present state, distribution, and cycling of water and carbon dioxide. Finally, there is one surface radiation objective: Characterize the broad spectrum of surface radiation, including galactic cosmic radiation, solar proton events, and secondary neutrons.

Four specific scientific objectives for habitability were also established. The first is to assess the biological potential of at least one target environment by determining the nature and inventory of organic carbon compounds, searching for the chemical building blocks of life, and identifying features that may record the actions of biologically relevant processes.

The second objective is to characterize the geology of the landing region at all appropriate spatial scales by investigating the chemical, isotopic, and mineralogical composition of surface and near-surface materials, and by interpreting the processes that have formed rocks and soils.

The third is to investigate planetary processes relevant to past habitability (including the role of water) by assessing the long-timescale atmospheric evolution and determining the present state, distribution, and cycling of water and carbon dioxide.

The fourth objective for habitability involves surface radiation and is the same as the scientific goal described in that category.

All of this was supposed to begin with a launch this year. But as vehicle testing continued, hardware problems increased, and by late 2008 it was clear that the launch to Mars, scheduled in a window that will close late this month, would not be possible.

"We will not lessen our standards for testing the mission's complex flight systems, so we are choosing the more responsible option of changing the launch date," said Doug McCuistion, headquarters director of Mars exploration. Since the launch window for a Mars mission opens only every two years, the agency was now aiming at 2011—and even that would be a challenge. Technical problems had raised budget pressure on the project, to the point where cancellation was not out of the question. This ambitious mission had hit a bumpy trajectory while still in the lab. And

Like two pieces of a giant clam, the aeroshell's backshell (above) and heat shield (below) come together to protect the rover and the propulsion stage that safely delivers it to the surface of Mars.

therein lies a tale of too much mission and not enough time—or money.

Spacecraft details

The MSL rover will be contained inside a trans-Mars coast cruise stage and aeroshell with a heat shield. In a new design approach, the rover will deploy its wheels using a lanyard-hydraulic method much as an airplane drops its landing gear prior to landing.

The spacecraft assembly includes the aeroshell and related components that will hold the rover and shield the spacecraft as it enters the Martian atmosphere and descends. The spacecraft assembly—all hardware above the upper stage of the Atlas V launch vehicle—consists of the cruise stage, an entry descent and landing system of parachutes and crane-like hoist, and the wheeled Mars surface rover.

The encapsulated spacecraft aeroshell is reminiscent of the Viking landers that touched down on Mars in 1976. The rover design is based on Spirit and Opportunity, the rovers that landed on Mars in 2004. The entry and descent system, however, is of an entirely new design. Total launch mass is 7,500 lb.

A complex flight plan

Following launch aboard the Atlas V 541 booster, the cruise phase of the mission will begin after spacecraft separation. During the year-long coast, spacecraft health and system calibrations are to be performed. If the trajectory requires them, small midcourse correction burns by the vehicle's onboard propulsion system will be fired. This will ensure that the spin rotation that began following separation continues in such a way that the spacecraft's antennas remain aimed at Earth and the solar panels at the Sun, because solar energy powers the spacecraft during this period.

As MSL approaches Mars, a number of final preparations are planned, including final trajectory midcourse correction maneuvers. Small attitude pointing updates will be sent to the craft, ensuring antenna alignment for entry communications. Frequent "delta DOR" measurements will be taken to orient the spacecraft position for entry into the atmosphere. On board, the software for the entry will be loaded and activated. The first of several surface sequences and communication windows for the first "sol" (Martian day) will be loaded into the computer. During the approach phase, NASA will use the Deep Space Network increasingly, to determine more accurate trajectory data as the vehicle nears the planet. The DSN's 34-m and 70-m antennas will both be used.

At 78 mi. above the planet, the entry, descent, and landing phase will begin. Using small rockets, the spacecraft will make its final orientation to the atmosphere. The encapsulated descent stage/aeroshell will separate from the cruise stage and will be positioned for entry, the blunt end of the pica-coated heat shield facing the flight path.

The MSL will feature the first soft-landing system used in a robotic Mars mission. After the parachute has significantly slowed the vehicle's descent and the heat shield separates, the descent stage will separate from the backshell. Using four steerable engines, the descent stage will slow down the nested rover even further to eliminate the effects of any horizontal winds. When the vehicle has been slowed to nearly zero velocity, the rover will be released from the descent stage. A bridle and "umbilical cord" will lower the rover to the ground. During the lowering, the rover's

Engineers took the MSL rover for a test drive in the lab. The "Scarecrow" engineering model, so named because it was still missing its computer brain, easily traversed large rocks in JPL's "Mars Yard."

front mobility system will be deployed so that it is essentially ready to rove upon landing.

When the onboard computer senses that touchdown is successful, it will cut the bridle. The descent stage will then pitch away from the rover and power away at full throttle to a crash-landing far from the MSL rover. If the atmospheric trajectory maneuvers are successful, a series of steerable S-turns will have oriented the descending spacecraft toward a narrow, targeted 12-mi. ellipse, much smaller than the 93-mi.x12-mi. ellipses that were the targets of Spirit and Opportunity. This smaller footprint will have been selected before launch, based on orbital photography. The principal means of communication between the rover and Earth will be radio relays between the rover and Mars orbiters.

Three minutes before landing, the spacecraft will deploy a parachute while the descent stage fires a series of retro rockets to slow the descent for the final 1,640 ft. The engines on the stage will slow the descent to a hover, at which point the rover will be dropped from the stage enclosure by a tether for the last several feet before touchdown.

Cameras mounted on a mast above the rover will help guide the spacecraft to specific surface targets. It will use a small nuclear-powered radioisotope power source that will give the mission a full Mars year (687 Earth days) of exploration. The wheeled system will be capable of rolling over obstacles up to 25 in. in size and traveling up to 660 ft each day.

The rover's mission will be to use its advanced suite of on-board instruments to gather rock and soil samples, crush the rocks, and distribute the samples inside the rover to a series of laboratories and test chambers for analysis. The instruments and equipment will be contained inside a rover body similar in design to the earlier rovers, using a rocker-bogie suspension system as before but with larger, six-wheel-drive wheels.

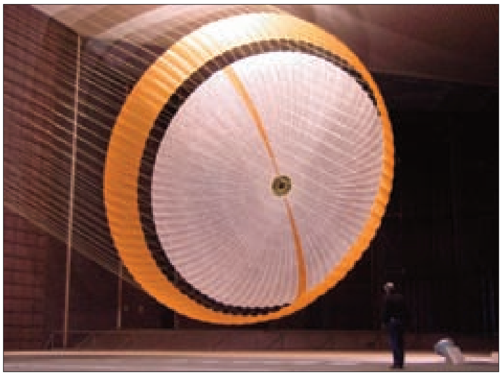
Hardware and software woes

For the tracked wheeled system, NASA at first chose a wet lubricant to coast the gears that drive the wheels. The wet lubricant system was selected because the MSL was designed to operate at much colder latitudes on Mars, notes NASA's McCuistion. "We then switched to a dry system because we didn't have to warm it up," he tells *Aerospace America*. "There were no additional heating require-

Mars Science Laboratory: Components

	Allocated Mass, kg	*Cumulative Mass, kg*
Rover	*850*	*850*
Descent stage (dry)	*829*	*1,679*
Descent stage propellant	*390*	*2,069*
Heat shield	*382*	*2,451*
Cruise stage (wet)	*600*	*3,051*
Backshell	*349*	*3,400*

Source: NASA JPL.



The team developing the landing system tested the deployment of an early parachute design in mid-October 2007 inside the world's largest wind tunnel, at NASA Ames.

ments," he adds. The design of the gears was shifted from steel gears to titanium because of the desire to reduce weight and mass. "It was much lighter. But the dry film on the titanium [gears] didn't work—the titanium gears were unable to hold the stress," says McCuistion. Dry film would not stay on the gears, or adhere to the metal. NASA then made the decision to change back to a steel gear design—and with it, wet lubricants.

These problems were identified during early development, he pointed out, but also drove up costs and development time. The actuators—which are bearings in the motors' motor encoder-gear box—was where the lubricant issue first emerged. "The bearings in the motors were not able to meet the launch date, and made the motor unstable. The electronics couldn't handle the unstable motors," McCuistion observes.

There also were issues involving the avionics software. Software for a spacecraft, in this case the rover, is constructed in "builds" during different phases of test and development. As different instruments are activated, different software also is activated and comes on line. Software during cruise phase while the spacecraft is enroute to Mars will be fine-tuned. But the final design of the software has yet to be completed, because the hardware itself is still under development.

"We can't finalize all of the software until the hardware is finished," McCuistion says. Several major components are still not finished—and some of what originally was to be validated during cruise flight will now be done on the ground. The motor control avionics are not yet done, and landing radar is not yet finalized. But McCuistion says they were of a "brand new design, better than previous rovers. Better capability."

One area of good design news concerns the pica heat shield, now under final testing. The pica has sufficient heat resisting ability that if the final trajectory is changed to a "hotter" atmospheric entry, the shield as designed has sufficient extra margin to easily accommodate the change. While these design and hardware constructions are under way, science teams are evaluating four potential landing footprints. The teams will meet for a review in late winter 2010, with the possibility of adding a fifth candidate for final analysis. The exact entry and landing targets will be selected in late 2010 or early 2011.

The cost factor

"Cost and schedules are taken very seriously on any science mission," said NASA's Ed Weiler, associate administrator for science, at a news conference discussing the project's delays. "However, when it's all said and done, the passing grade is mission success." Weiler says the decision to slip the launch, while not good news, reflects greater accountability at NASA for the programs it manages. He says that in the late summer of 2008 his directorate first received the cost overrun on the Mars program. Mars program officials were optimistic that a 2009 launch could be met. "I asked the question, [when] will you reach a point where you'll not be able to stay within your budget for that fiscal year?" he recalls. He decided to establish weekly milestones to track the program's progress. "That's unusual for headquarters," he adds.

By late November 2008 it became clear the project was starting to slip. JPL also did a review that confirmed the findings. So a decision was made in early December that the 2009 launch could not be met. "We made the decision not to spend one extra penny and to basically back off two years," Weiler says. He adds that headquarters still has a weekly milestone tracking for MSL in place.

Weiler blames technology and optimistic assumptions for the program's troubles. "Too many technologies having to all fit together…the optimistic assumptions that contractors could build things and make them work the first time at cryogenic temperatures, Mars temperatures. Too many things coming together," he says, adding that MSL's initial budget was "based on a lot of hope…and hope is not a management tool."

With so much of the MSL hardware and software still in assembly, if not design, and the program's budget under constant monitoring because of past cost overruns, the Mars Science Laboratory may yet face the hardest part of its ambitious mission long before the Atlas ever leaves the ground.