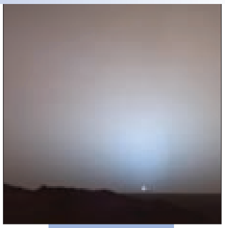

Endurance near and (really) far

ENDURANCE IS A VALUABLE CHARACTERISTIC for vehicles that are either remotely piloted or robotic. One such vehicle, currently under development by the Navy, is expected to stay in the air for 24 hr. And two of NASA's robotic vehicles—the Mars rovers Spirit and Opportunity—have remained in operation far longer than their original mission objectives.

The power of the fuel cell

The military services use UAVs to scan terrain for possible threats and other intelligence. Now, fuel-cell-powered UAVs are taking flight as an Office of Naval Research-sponsored program to help tactical decision-makers gather critical information more efficiently and more quietly.

Piloted remotely or autonomously, UAVs have long provided extra eyes in the sky, especially for missions too dangerous for manned aircraft. This latest technology—fuel cell power—is showcased by Ion Tiger, a UAV research program at the Naval Research Laboratory that merges two separate efforts: UAV technology and fuel cell systems.

In particular, the Ion Tiger tests a hydrogen-powered fuel cell design that will allow the UAV to travel farther than earlier battery-powered designs and carry heavier payloads. Ion Tiger also exhibits stealthy characteristics because of its small size, reduced noise, low heat signature, and zero emissions. (A video of Ion Tiger in action is available at http://www.onr.navy.mil/media/article.asp?ID=178.)

"Pursuing energy efficiency and energy independence are core to ONR's power and energy focus area," says R. Adm. Nevin Carr, chief of naval research. "ONR's investments in alternative energy sources, like fuel cell research, have application to the Navy and Marine Corps mission in future UAVs and vehicles. These investments also contribute directly to solving some of the same technology challenges faced at the national level."

Fuel cells create an electrical current when they convert hydrogen and oxygen into water, and they are pollution free. A fuel cell propulsion system also delivers potentially twice the efficiency of an internal combustion engine, while running more quietly and with greater endurance.

The Navy's Ion Tiger UAV operates with a high-powered fuel cell propulsion system. (Credit ONR)

"In this size range, we are hopefully able to conduct very productive surveillance missions at low cost with a relatively small vehicle and a high-quality electric payload," says Karen Swider-Lyons, NRL principal investigator.

Researchers expect that Ion Tiger's flight trial will exceed the duration of previous flights by sevenfold, from 3 hr to 24 hr.

The UAV uses a 500-W polymer fuel cell with a high specific power system. High-pressure, lightweight hydrogen storage tanks are used to decrease weight. The fuel cell produces little noise and emits less infrared energy than traditional engines or batteries.

Previously flown with batteries, the Ion Tiger has demonstrated sound aerodynamics, high functionality, and low heat and noise signatures.

"This will really be a first-of-its-kind demonstration for a fuel cell system in a UAV application for a 24-hr endurance flight, with a 5-lb payload," says Michele Anderson, the ONR program manager. "That is something nobody can do right now."

In 2005, NRL backed initial research in fuel cell technologies for UAVs. That support is paying off today with a few lessons learned from the automotive industry, says Swider-Lyons.

"With UAVs, we are dealing with relatively small fuel cells of 500 W," she explains. "It is hard to get custom, high-quality fuel cell membranes built just for this program. So we are riding along with this push for technology from the automotive industry.

"What is different with fuel cell cars is that developers are focused on volume. So they want everything very compact," adds Swider-Lyons. "Our first issue is weight, our second issue is weight, and our third issue is weight."

Broad applications

Besides delivering energy savings and increased power potential, fuel cell technology spans the operational spectrum, from ground vehicles to UAVs to man-portable power generation for Marine expeditionary missions to meeting power needs afloat. In fact, it is technology that Marines at Camp Pendleton are using today to power their General Motors fuel cell vehicles.

Across the board, the Navy and Marine Corps are seeking more efficient sources of energy. ONR has been researching and testing power and energy technology for decades. Often the improvements to power generation and fuel efficiency for ships, aircraft, vehicles, and installations yield a direct benefit to the public.

"ONR has been a visionary in terms of providing support for this program," says Swider-Lyons.

Other Ion Tiger partners include Protonex Technology in Southborough, Mass., and the University of Hawaii. NRL's work on UAVs also leverages funding from the Office of the Secretary of Defense.

Researchers at the University of Hawaii will use a $250,000 grant from the Dept. of Defense to conduct research for improvement of power sources for small military systems via materials and systems development.

Protonex manufactures long-duration portable and remote power sources. It provides complete power solutions, fuel cell stacks, and application services to original equipment manufacturers for portable and remote off-grid applications poorly served by existing battery, generator, solar, and other power technologies. Protonex's fuel cell technology complements existing power technologies and is used in hybrid designs for customer applications in the 10-1,000-W power range.

And speaking of endurance...

The staying power exhibited by the two Mars rovers is remarkable. In January 2004, NASA landed the two identical robotic rovers, Spirit and Opportunity, on the surface of Mars. The twins were primed for a brief three-month mission to find information about water and possibly life in the planet's past. More than five years later, the two still rove the planet. It is a saga of overachievement that has transformed Mars exploration.

"Spirit and Opportunity helped invent a whole new discipline—robotic field science," says Steve Squyres, principal investigator for the Mars Exploration Rover mission. "They have taught us how to organize large teams of scientists and engineers to operate robotic rovers on a distant planet. We all had to learn to work together effectively year after year to squeeze the most possible science from the rovers."

These solar-powered robots found that Mars was not always as cold and dry as it is today. It had water and was warm enough for life.

The Mars exploration mission team members have also learned the perils of maneuvering robotic rovers located 100 million km away. They have gotten the vehicles stuck more than once. "We now know how to negotiate sand dunes and piles of rocks," says Squyres, "and perhaps more importantly, how to avoid them. We have translated five years of experience into new and improved maps and driving software that will help us in the remainder of our mission and will also help future rovers."

Hopeful planners are already setting future operations for the twins, assuming they will continue to plow ahead but acknowledging that one or both of the rovers could fail at any time. Spirit has been driving backwards since one of its wheels jammed in 2006, and a broken electrical wire has limited the movement of Opportunity's robotic arm.

Provided the twins hold up a while longer, here are the latest plans:

Opportunity, "the lucky vehicle since day one," according to Squyres, has been crater-hopping since the start of the mission and is now heading south to the largest one yet—Endeavour crater is 20 km across and hundreds of meters deep.

"We will have to double the odometer reading on a five-year-old vehicle to get there," says Squyres. "And it will take at least two years to reach it." An average day for Opportunity is 100 m per day. "It'll be a long march across the plains, but it will be well worth it," he says. "The deeper the crater, the older

Spirit's complications

The problems that the rover teams have had to confront are exemplified by several incidents that occurred at the end of April. Spirit had a bout of temporary amnesia April 17, and rebooted its computer on April 18, behavior similar to events that occurred about a week earlier.

Engineers operating Spirit are investigating the reboots and the possibly unrelated amnesia events, in which Spirit unexpectedly failed to record data into its flash memory, where information is preserved even when power is off. Spirit had three amnesia events in April, plus one on January 25. The team could not determine if there was a causal link between the amnesia events and the reboots.

The most recent reboot put Spirit into an autonomous operations mode in which the rover keeps itself healthy. Spirit experienced no problems in this autonomous mode. "We are proceeding cautiously, but we are encouraged by knowing that Spirit is stable in terms of power and thermal conditions and has been responding to all communication sessions," says JPL's Sharon Laubach, chief of the rover sequencing team, which develops and checks each day's set of commands.

During the diagnostic activities, the rover successfully moved its high-gain dish antenna and its camera mast, part of checking whether any mechanical issues with those components may be related to the reboots, the amnesia events, or the failure to wake up for three consecutive communication sessions in April.

Engineers have found ways to cope with various symptoms of aging on both rovers. The current diagnostic efforts with Spirit are aimed at either recovering undiminished use of the rover or, if some capabilities have been diminished, determining the best way to keep using the rover.

Laubach says, "For example, if we do determine that we can no longer use the flash memory reliably, we could design operations around using the random-access memory." Spirit has 128 MB of random-access memory, which can store data as long as the rover is kept awake before its next downlink communications session.

the history of Mars we can look at."

Ray Arvidson, deputy principal investigator, elaborates: "Endeavour is an intriguing target because the rocks close to it look different from the ones surrounding the other craters Opportunity has visited. Part of Endeavour crater's rim is sticking up—Mars' ancient bedrock exposed—and rocks nearby may be suggestive of acidic lakes on Mars' surface billions of years ago."

"Spirit is the more challenging rover to operate," notes Squyres. "There is not as much wind at its location to clean the solar arrays, and that affects the vehicle's power. Also, Spirit has to travel a more challenging terrain. The rocks and loose sand at Spirit's location are treacherous. Of course, to top it all off, Spirit is driving backwards.

"Luckily, Spirit's landing site features a compact geology with enormous diversity and variability in a small area," says Squyres.

Opportunity looks back on its own tire tracks en route to Endeavour crater. (Credit NASA)

Spirit is now creeping steadily along a route to von Braun, an interesting looking mesa-shaped cap-rock that stands only about 250 m away but will take months to reach. Then Spirit will head to a 30-m-diam pit that may be a volcanic explosion crater and perhaps a location for hydrothermal activity.

"Because of the geology of its surroundings, Spirit specializes in looking for evidence in the rock record of water-charged explosive volcanism," Arvidson says. "Such areas could once have supported life.

"Home Plate, where Spirit spent the winter, is a volcanic structure eroded down so we can see the layers," explains Arvidson. "And we think von Braun and the neighboring Goddard structure may be made of the same stuff."

The Mars exploration team members have high hopes that the rovers can achieve all these ambitious goals but are mindful of the twins' limitations.

"We have no way of knowing what the future holds for the rovers at this point," says Squyres. "The mission could easily end tomorrow. Or, the miracle could continue."

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