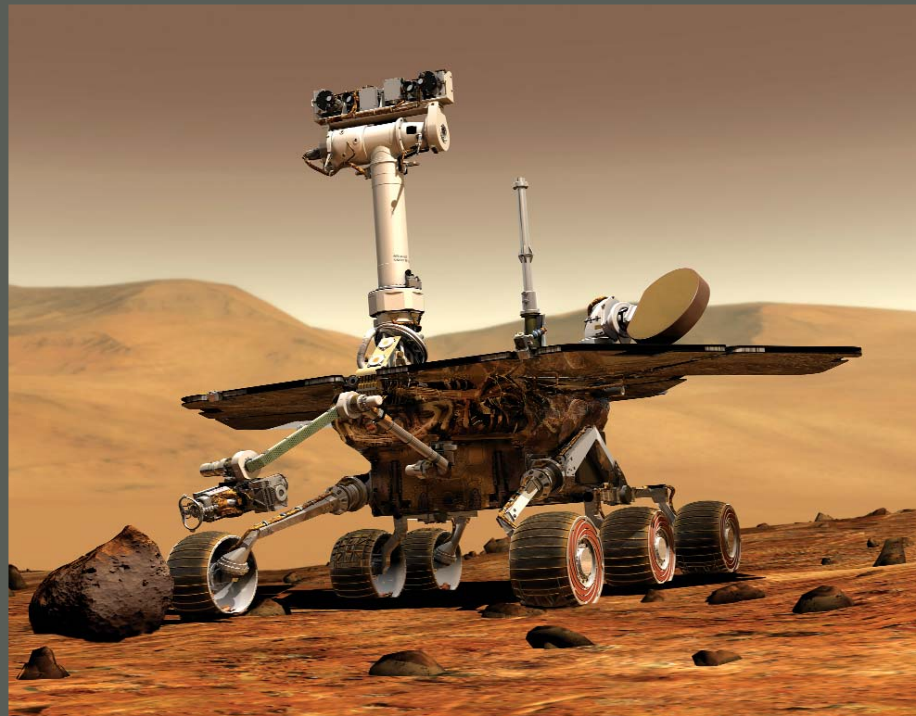


Martian Robot Update

by Jim Oberg

Traditionally, robots are hard to kill. There's no better current example of that characteristic than the extraordinary lifetimes of the two golf-cart sized robot rovers on Mars, 'Spirit' and 'Opportunity.' Designed for a 90-day surface sojourn, both robots were well into their second YEAR of operation when these words were written.

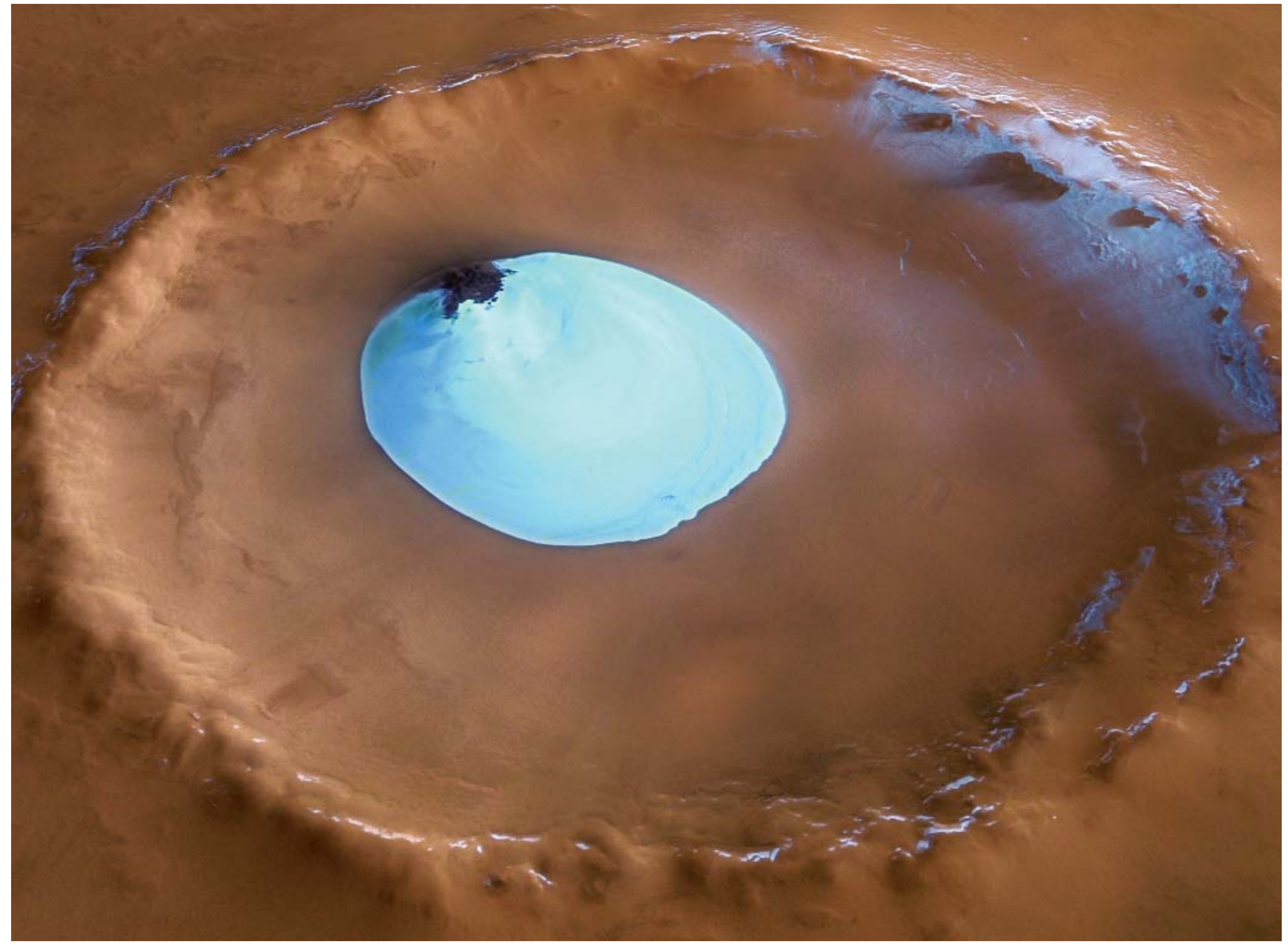
But modern robots are also fairly stupid, and can be counted on to follow literal instructions even if it kills them. Both rovers barely escaped death on Mars in this fashion. Obeying its software, 'Spirit' kept overloading its computer memory until it suddenly suffered a nervous breakdown that for a while looked terminal. Obeying its driving directions, 'Opportunity' crested a sand dune and began °sinking into the talcum-powder soft surface – but kept running its wheels blindly, digging itself so deep that it took a month of planning and wheel-spinning to get loose.

And robots are expected to surprise their creators, just as these two Mars machines have done. Amazingly, both of them didn't make their most exciting scientific discoveries until well after their warranty periods had expired. And astonishingly, while the limiting lifetime factor was expected to be a gradual buildup of wind-blown dust on solar arrays that would ultimately starve the robots for power, both machines repeatedly experienced 'cleaning events' – probably overnight windstorms – that kept on removing the dust and restoring full power levels.

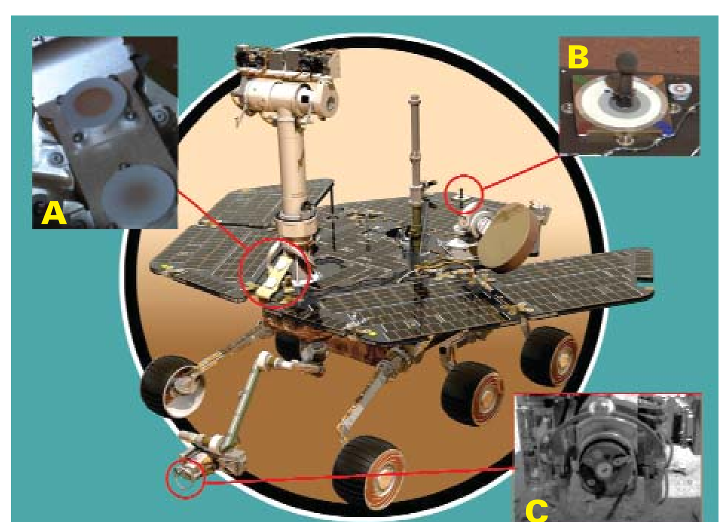
So what makes these Mars robots tick? Read on for a look under the hood of these amazing vehicles.

PHOTOS AND ILLUSTRATION PROVIDED BY JPL/NASA

NASA's Mars Exploration Rover Spirit captured this view of a Martian sunset at 6:07 in the evening on May 19th, 2005. The sun, two-thirds the size it would appear as seen from Earth, is sinking below the rim of Gusev crater. This small panorama of the western sky was obtained using Pancam's 750-nanometer, 530-nanometer and 430-nanometer color filters. The bluish glow in the sky would be visible to the human eye, but the redness farther from the sunset is slightly exaggerated by Spirit's robot Pancam imaging system. See additional photos at http://marsrovers.jpl.nasa.gov/home/index.html.



Another robot, the European Space Agency's Mars Express Orbiter, took this photo of a large sheet of water ice in July 2005, which was late summer in the Martian northern hemisphere. The unnamed crater is 35 kilometers wide, and the miles-wide patch of water ice is present year-round. For more images taken by the orbiter robot, see www.esa.int/SPECIALS/Mars_Express.



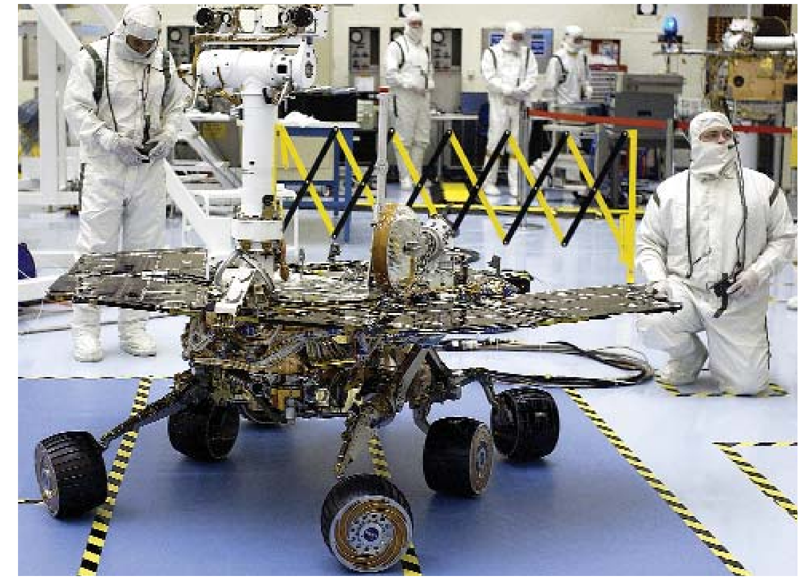
Details: (A) dust collection magnets, (B) color calibration sheets with sundial (provided by Planetary Society) and (C) rock abrasion tool.

A LOOK UNDER THE HOOD

The Rover 'body' is called the WEB (Warm Electronics Box). Its gold-painted, insulated body walls keep heat in when the night temperatures on Mars can drop to -96º Celsius (-140º Fahrenheit)! The body contains a UHF (Ultra High Frequency) antenna, X-band telecommunications hardware, a navigation unit, a guidance computer, and a camera mast. Each Rover has a top speed on flat, hard ground of two inches per second.

There are a total of nine television cameras on each Rover: Four black-and-white Hazard Avoidance Cameras (Hazcams) are mounted on the lower portion of the front and rear of the Rover; they capture threedimensional (3-D) imagery used by the Rover brain for steering. Two black-and-white Navigation Cameras (Navcams) are mounted on the mast gather panoramic, three-dimensional (3D) imagery to support ground navigation planning by scientists and engineers. Two color Science Panoramic Cameras (Pancams) are mounted on the Rover mast and deliver 3D panoramas of the Martian surface. The narrow field of view and height of the cameras basically mimic the resolution of the human eye. The cameras are small enough to fit in the palm of your hand (about 9 ounces), but can generate panoramic image mosaics as large as 4,000 pixels high and 24,000 pixels around. The mast assembly acts as a periscope for the spectrometer science instrument that is housed inside the Rover body, and it provides height and a better point of view for the Panoramic Cameras and the Navigation Cameras. Motors can turn the cameras full circle, or tilt them straight up or down.

At the end of the Rover's arm is a cross-shaped turret, a handlike structure that holds various tools that can spin through a 350-degree turning range. Almost a third of the weight of the titanium robotic arm comes from the four instruments it holds at the end of the arm. The Rock Abrasion Tool is a powerful grinder, able to create a hole 45 millimeters (about 2 inches) in diameter and 5 millimeters (0.2 inches) deep into a rock on the Martian surface. The forearm also holds a small brush so that the Rock Abrasion Tool can spin against it to "brush its teeth" and rid the grinding tool of any leftover pieces of rock before its next bite.



The Mars Exploration Rover has six wheels, each with its own individual motor. the two front and two rear wheels also have individual steering motors (1 each). These Rovers can turn a full 360 degrees in place, and can swerve and curve while driving.

When one side of the Rover goes up (say, rolling over a rock), the rocker in the "rocker-bogie" suspension system automatically makes the wheels on the other side go down to even out the weight load. This system causes the Rover body to go through only half of the range of motion that the "legs" and wheels experience. The Rover can drive over obstacles (such as rocks) or through holes that are more than a wheel diameter (25 centimeters or 10 inches) in size. Each wheel also has cleats, providing grip for climbing in soft sand and scrambling over rocks.

One black-and-white Science Micro-scopic Imager is mounted on the robotic arm to take extreme close-up pictures of rocks and soil.

ENERGY AND BRAINS

The Rover solar arrays can generate about 140 watts of power for up to four hours per Martian day. The Rover needs about 100 watts to drive. The power system for the Rover includes two rechargeable batteries that provide energy for the Rover at night.

The Rover computer contains special memory to tolerate the extreme radiation environment from space and to safeguard against power-off cycles so that programs and data will not accidentally erase when the Rover shuts down at night. On-board memory is roughly the equivalent of that of a standard home PC (each Rover has 128 MB of DRAM and 3 MB of EEPROM).

COMMUNICATING WITH EARTH

The Rover has both a low-gain and high-gain antenna that serve as both its "voice" and its "ears". They are located on the Rover equipment deck (its "back"). The low-gain antenna sends and receives information in every direction; that is, it is "omni-directional." The antenna transmits radio waves at a low rate to the Deep Space Network (DSN) antennas on Earth. The high-gain antenna can send a "beam" of information in a specific direction, so the antenna can move to point itself directly to any antenna on Earth.

Not only can the Rovers send messages directly to Earth, but they can uplink information to other spacecraft orbiting Mars. The orbiters can also send messages to the Rovers. The data rate direct-to-Earth is roughly a third as fast as a standard home modem (3,500 to 12,000 bits per second). The data rate to the orbiters is four times faster than a typical dialup home modem (128,000 bits per second).

All of this hardware exists only to enhance the 'wetware' of human brains back on Earth, and these Mars roving robots have fulfilled and over-fulfilled original intentions. Aside from the serious science, they have relayed amazing vistas of the strange world around them – looking downhill across the floor of Gusev crater to the crater rim on the horizon; gazing at the sky and catching meteor fireballs streaking by; watching a sunset; producing rapid-frame imagery of dust devils twisting across the landscape; focusing in on exotic-looking rocks, paper-thin soil layerings, 'blueberry' nodules, and other items as yet unrecognizable and unidentifiable.

These are the smartest and luckiest space robots ever sent into space–and they are just the beginning.

Below: This stunning image features the heat shield impact site of NASA's Mars Exploration Rover Opportunity. This is an approximately true-color mosaic of panoramic camera images taken through the camera's 750-, 530-, and 430-nanometer filters.