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EXPLORING MARS WITH SOLAR-POWERED ROVERS

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ABSTRACT

The Mars Exploration Rover (MER) project landed two solar-powered rovers, "Spirit" and "Opportunity," on the surface of Mars in January of 2003. This talk reviews the history of solar-powered missions to Mars and looks at the science mission of the MER rovers, focusing on the solar energy and array performance.

MARS

Mars is the next planet outward from the sun, and in many ways is the planet in the solar system that most resembles the Earth. There is a great deal of interest in exploring and understanding the planet Mars. The NASA program for exploring Mars has funded missions to send a spacecraft to Mars during each of the upcoming launch windows (roughly every 2.2 years) through the end of the decade. Future missions beyond this time frame, both robotic and human, are being planned.

Exploration of the planet Mars has been a challenging undertaking. At the time of the launch of the MER rovers in 2003, two out of three of the missions sent from Earth to orbit or land on Mars failed.

POWER FOR MISSIONS TO MARS

The first missions to successfully land on the surface of Mars, the 1976 Viking landers, were powered by radioisotope thermoelectric generators ("RTG"s).

The first solar-powered mission to the planet Mars was the "Pathfinder" mission, which landed in 1997. Pathfinder used GaAs on Germanium cells for both the lander, and also for the "Sojourner" rover [1]. The rover is shown in Figure 1.

The Martian surface environment provides peculiar challenges for the operation of solar arrays [2, 3]: low temperature, reduced solar flux reaching the surface due to atmospheric dust [3-7] with a significant scattered component which varies in intensity and spectrum with the amount of suspended atmospheric dust, and the possibility of performance loss due to dust deposition on the array surface.

The radiation environment includes ultraviolet (UV) and some particulate radiation. The radiation at the surface of Mars is much lower than that of the orbital environment. Mars has no trapped radiation belts, and the Martian atmosphere serves as a radiation shield with a mass of fifteen to twenty-five grams per square centimeter (depending on season and altitude) against coronal mass-ejection ("solar flare") events. This is equivalent to a thickness of 5 to 9 centimeters of aluminum.

Dust deposition on the arrays has been an area of significant interest. A measurement using the Materials Adherence Experiment (MAE) on the Sojourner rover showed a degradation of the solar array performance by about 0.28% per sol for the first 30 sols of the mission [8,9]. A "sol" is a Mars solar day, 24 hours and 40 minutes. Measurements of the dust deposition on the lander arrays was more difficult due to the unfortunate coincidence of the landing orientation, which put the shadow of the meteorology mast on the Isc measurement solar cell at noon. The data appeared to show that the rate of dust deposition decreased after about the first 30 sols [1, 7].

A solar array experiment [10] and a dust measurement experiment [11] were developed and built to fly as part of the science package of the 2001 Mars Surveyor lander mission. Unfortunately, as a result of the loss of the 1998 Mars Polar Lander and Mars Climate Orbiter missions, the risks involved in the spacecraft for the 2001 Surveyor lander mission were judged to be too high, and the mission was cancelled.

Due to the Pathfinder results, there has been some interest in developing means to mitigate the effect of dust on the solar arrays for long-duration operation on Mars [11, 12]. However, for the Mars Exploration Rover mission, with a target of 90 sols of operating lifetime on Mars, the engineering decision was that it would be more cost effective to oversize the arrays to account for the predicted degradation than it would be to fly an (untested) system to remove dust from the panels.

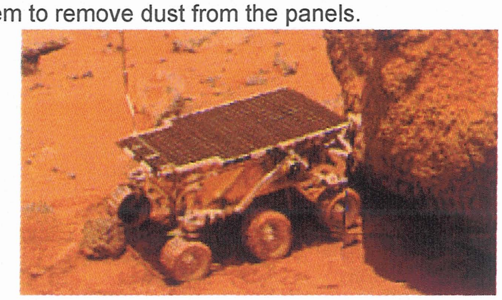

Figure 1. The 1997 Pathfinder mission included the small solar-powered Sojourner rover.

THE MARS EXPLORATION ROVERS

The Mars Exploration Rovers were about twice as large as Sojourner in all dimensions, and were designed to a 90-sol operating lifetime on Mars (as opposed to the 7-sol design lifetime of the Sojourner rover. Sojourner actually functioned for about 80 sols).

The MER rover is shown in artist's conception in figure 2, and a pre-launch view of one of the solar array is shown in figure 3. Solar cells are mounted on the main deck, and on five fold-out panels (two each on the left and right side, and one at the rear). The power system for the MER rover used triple-junction "ITJ" solar cells, and a rechargeable lithium-ion battery. More details on the design of the solar arrays for both the cruise spacecraft and the rover can be found in the paper by Stella *et al.* [13]. One of the solar array panels is shown in Figure 3.

On Mars, the performance of the solar arrays is limited by the top GaInP junction of the three series-connected subcells, responsive to the blue wavelengths of the spectrum. A measured spectral response of this top subcell is shown in Figure 4. The spectral response varies slightly with temperature. Since the operating temperature varies significantly during the day, and the spectrum of the incident sunlight varies both with time of day and with the amount of dust in the atmosphere, the performance of the solar arrays on Mars is complicated.

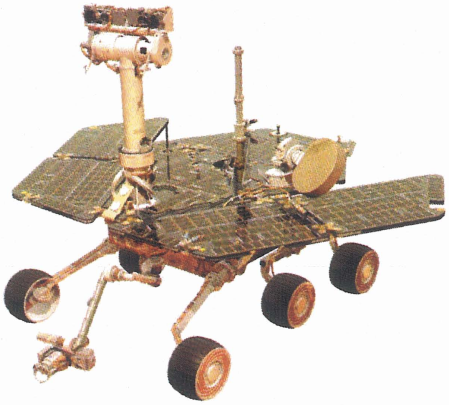

Figure 2. The Mars Exploration Rover (artist's conception). The two main cameras, the pancam and the navigation cameras, are on top of the mast. The solar arrays comprise the body-mounted cells on the center, and five fold-out panels [13].

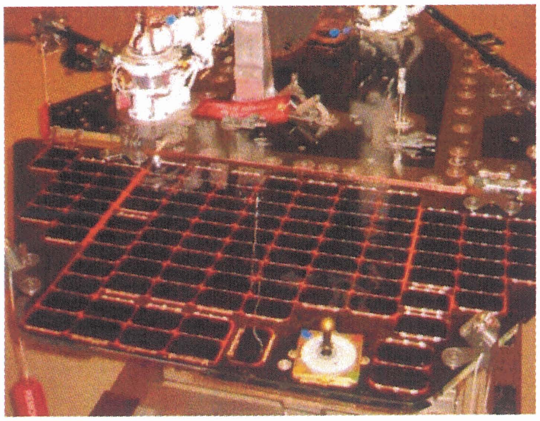

Figure 3. The rear, or "-X" panel of the MER solar arrays, shown before launch. The short-circuit current monitoring solar cell and the open-circuit voltage monitoring cell are mounted on the back (on the right, in this view).

Each of the rovers incorporates a solar cell to measure the short-circuit current, and one to measure the open-circuit voltage, during operation. These are mounted on the rear panel of the arrays (figure 3).

OPERATING ON MARS

Both rovers, Spirit and Opportunity, are operating well on the surface of Mars and are returning exciting scientific findings [14, 15]. Figure 5 is one of the first "self portraits" of the lander, showing the solar arrays fully deployed and operating on the surface of Mars. Figure 6 shows data from the monitoring solar cell for the first day on Mars, showing the short-circuit current rising during the course of a day to a peak at noon.

The optical depth (a measure of the amount of dust in the atmosphere) at landing was about 1, twice as high as that seen at Ares Vallis during the Pathfinder mission.

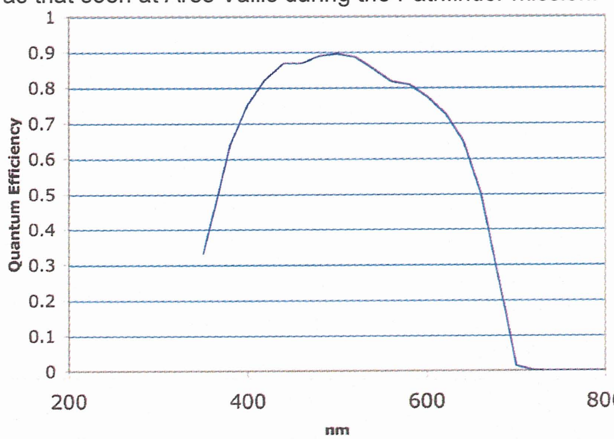

Figure 4. External spectral response of top junction of one of the triple-junction cells used on the MER solar array (measured by David Scheiman, NASA GRC).

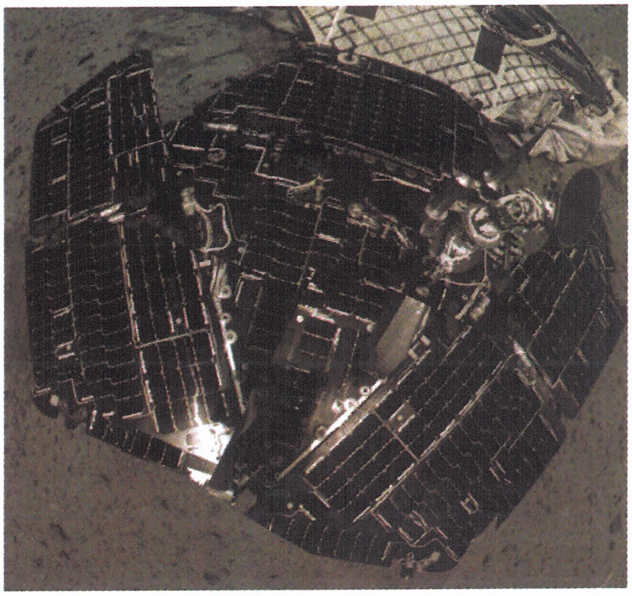

Figure 5. Self-portrait of the "Opportunity" rover after landing on Mars, looking down on the solar arrays from the navigation camera on top of the mast. (Image is distorted slightly by the fish-eye perspective.)

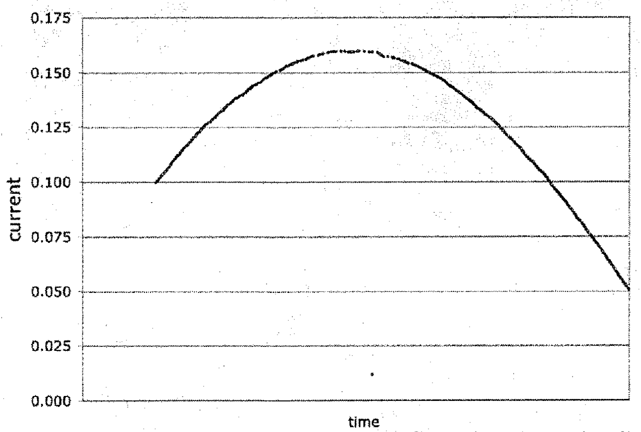

Figure 6. The first sol on Mars: data from the short-circuit current monitoring solar cell on the Spirit rover.

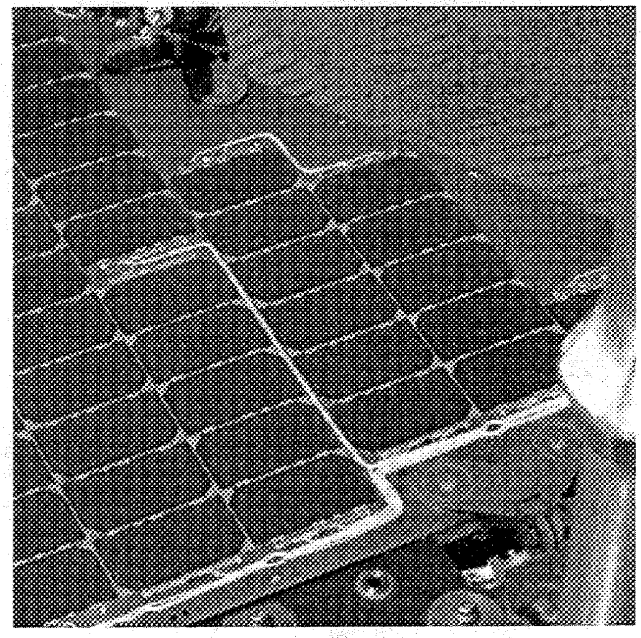

Figure 7. Opportunity solar arrays after 336 sols on Mars

The higher optical depth resulted in a slightly lower solar intensity on the arrays than pre-launch predictions, and had the unanticipated benefit that the shadowed parts of the arrays were not as dark as anticipated, due to scattered light. The optical depth declined during the mission, except for a brief period of high optical depth (a minor dust storm) shortly after New Year's day.

On of the first day of this conference, the rover Spirit celebrated its first full (Earth) year of operation on the surface of Mars, including operating at the middle of the Martian winter. Both rovers have well exceeded their design lifetime of 90 sols of operation. Figure 7 shows the solar arrays on Mars, still in fine shape after 330 days of operation.

Dust deposition has turned out not to be a lifetime-limiting problem on the rover solar arrays. The initial few weeks of operation on Mars showed a degradation roughly matching the Pathfinder dust deposition results [6, 7], but the degradation rate decreased after the initial high rate, following the longer-term Pathfinder data [7].

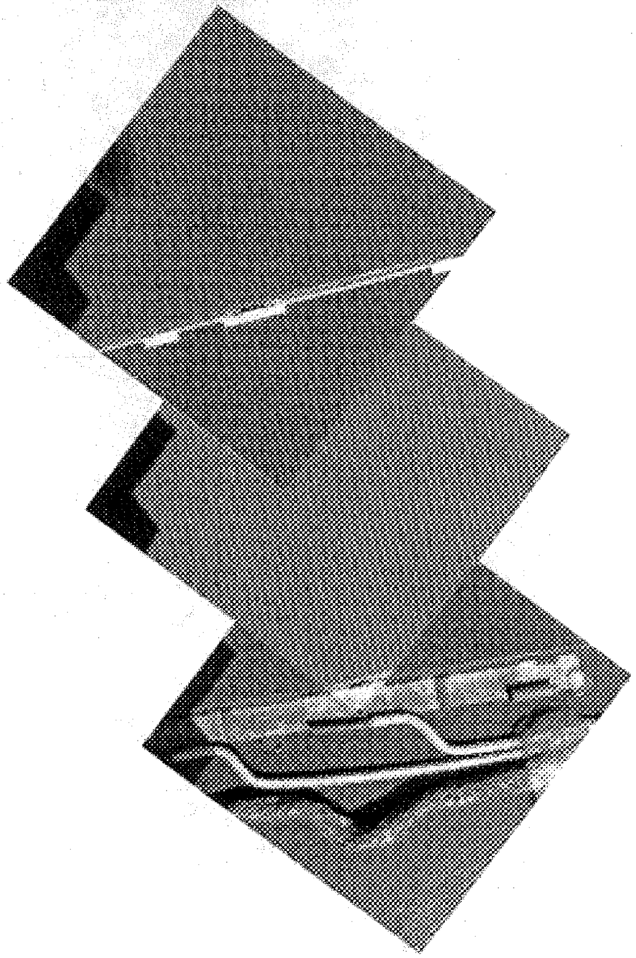

Figure 8: Three frames from the Microscopic imager, looking at the solar cells (and interconnects) at the front of the Spirit rover. (Each image is roughly 2.5 cm square.)

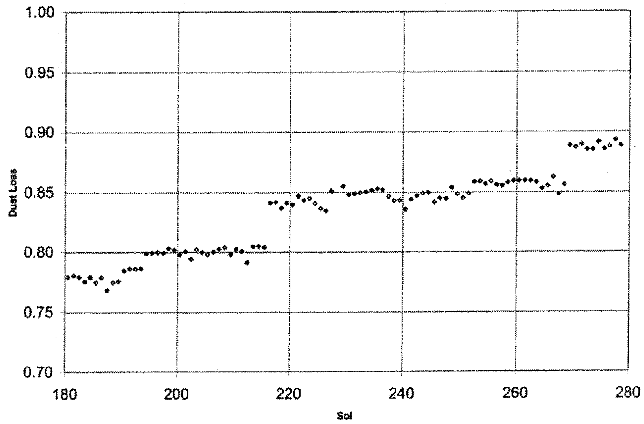

Figure 9. Loss of power due to dust coverage, estimated from the Isc solar cell on the Opportunity rover, sols 180-280. Note several abrupt rises in performance, indicating loss of dust in discrete events.

There is some evidence that the dust coverage has leveled out, either due to saturation of the dust, or due to a lower deposition rate in the winter, a season when there is less atmospheric dust. To learn more about the deposited dust, we examined at the solar cells on both rovers using the Microscopic Imager (MI). Figure 7 shows three frames from the MI on Spirit, looking at dust deposited on the solar cells after 11 months of exposure on Mars. Note that the surfaces were almost perfectly specular before launch.

Interesting, on the Opportunity rover, there were several events in the middle of the winter in which the degradation associated with dust actually decreased in several discrete events, indicating dust being removed from the arrays (Figure 9).

FUTURE MISSIONS

Several future missions to Mars are currently in progress. The next mission, launching in 2005, is the Mars Reconnaissance Orbiter, bringing a high-resolution camera to Mars orbit. Following this, the solar-powered "Phoenix" lander will be launched toward a landing in the north polar regions of Mars in 2007. This will be followed by the Mars Telecommunication orbiter and the Mars Science Laboratory (MSL), a large rover to be launched in 2009. The MSL is currently planned to use a radioisotope power system.

After the MSL, future robotic missions are currently under consideration, including long-duration rovers, a possible Mars airplane mission, and a mission to return a sample of Martian soil to the Earth. Following these missions, in the next few decades a human mission to Mars may be the next major goal of human exploration.

CONCLUSIONS

The Mars Exploration Rover mission successfully landed two solar-powered rovers on the surface of Mars in January 2004. A year after the landing, both rovers are continuing to operate successfully.

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