A DUST CHARACTERIZATION EXPERIMENT FOR SOLAR CELLS OPERATING ON MARS

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ABSTRACT

During the Viking and Pathfinder missions to Mars, significant amounts of dust accumulated on the spacecrafts. In Pathfinder's case, the dust obscured the solar panels on the lander and the rover degrading their output current. The material adherence experiment aboard the Pathfinder rover quantified the rate of decrease in short circuit current at 0.28% per day [**1**]. This rate is unacceptably high for long duration missions. In response, NASA has developed the Dust Accumulation and Removal Technology (DART) experiment. DART has 3 instruments for characterizing dust settling out of the atmosphere and tests two methods to keep dust from settling on solar cells.

MARS ISPP PRECURSOR (MIP)

The Dust Accumulation and Removal Technology (DART) experiment is one of five experiments on the Mars In-Situ Propellant Precursor (MIP) package [**2**]. The MIP package is a set of experiments designed to demonstrate on Mars the component technologies required to produce oxygen from the Martian atmosphere. MIP is part of a longer-term strategy for *in-situ* resource utilization (ISRU) on Mars.

DART will gather engineering data about the deposition rate and properties of dust that settles on the spacecraft and demonstrate the removal of dust [**3**]. By improving knowledge of the operating conditions of solar cells on Mars, the uncertainty in power output for future Mars missions can be reduced. A companion experiment, the Mars Array Technology Experiment, will test the operation of different solar cell types on Mars. Fig. **2** shows the flight layout for the DART and MATE experiments. The white line running through the photo roughly defines the MATE and DART halves of the experiment. The sensor descriptions for DART are detailed in the sections below. Details of MATE can be found in reference [4].

DART EXPERIMENT ACHITECTURE

A diagram of the system architecture is shown is fig. **2**. The two main components of DART are the top plate (fig. **1**) measuring 24 x 26 x 6 cm, and one 10 X 15 cm, 14 layer, electronics board. The DART experiment weighs approximately 750 grams including electronics. Nominal power consumption is 3 Watts for 20 minutes of operation per day. One Watt of survival power is provided during the Martian night. The exposed top plate was designed to survive +60°C to –110°C and the electronics from –55°C to +125°C.

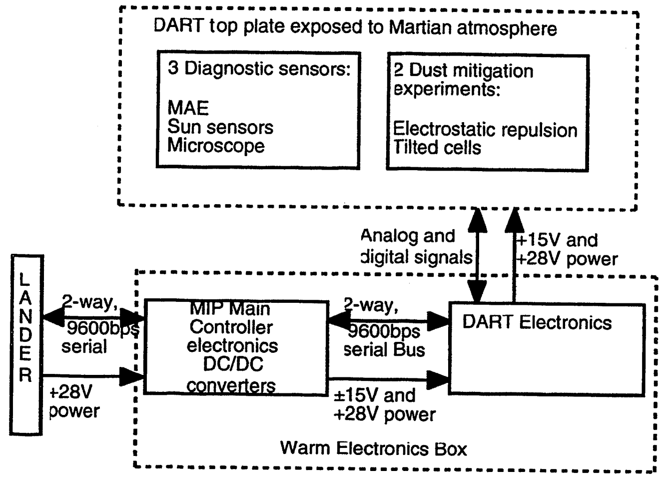

Figure 2) System schematic for the DART experiment.

On Mars, the top plate with all the dust sensors attached, is exposed to the sky. The electronics board is inside a warm electronics box. The top plate is electrically connected to the electronics board through 88 wires in two cables. The DART electronics takes voltage readings on 13 solar cells, reads three linear photodiode arrays, reads one 512x512 pixel CMOS imaging array, makes five temperature readings, drives two heater circuits and one actuator. All data is formatted into packets and forwarded to the MIP main controller. Which in turn forwards data to the Lander.

The DART experiment consists of five different instruments. The first three instruments listed below support the characterization of Mars dust. The last two instruments are experiments designed to mitigate dust build up on solar cells. In most cases single junction GaAs/Ge solar cells biased near short circuit were used to monitor dust build-up. These cells integrate most of the useful solar energy. In some instances GaInP single junction cells as well as GaAs cells filtered through a GaInP window layer provide some spectral resolution to the effects of dust.

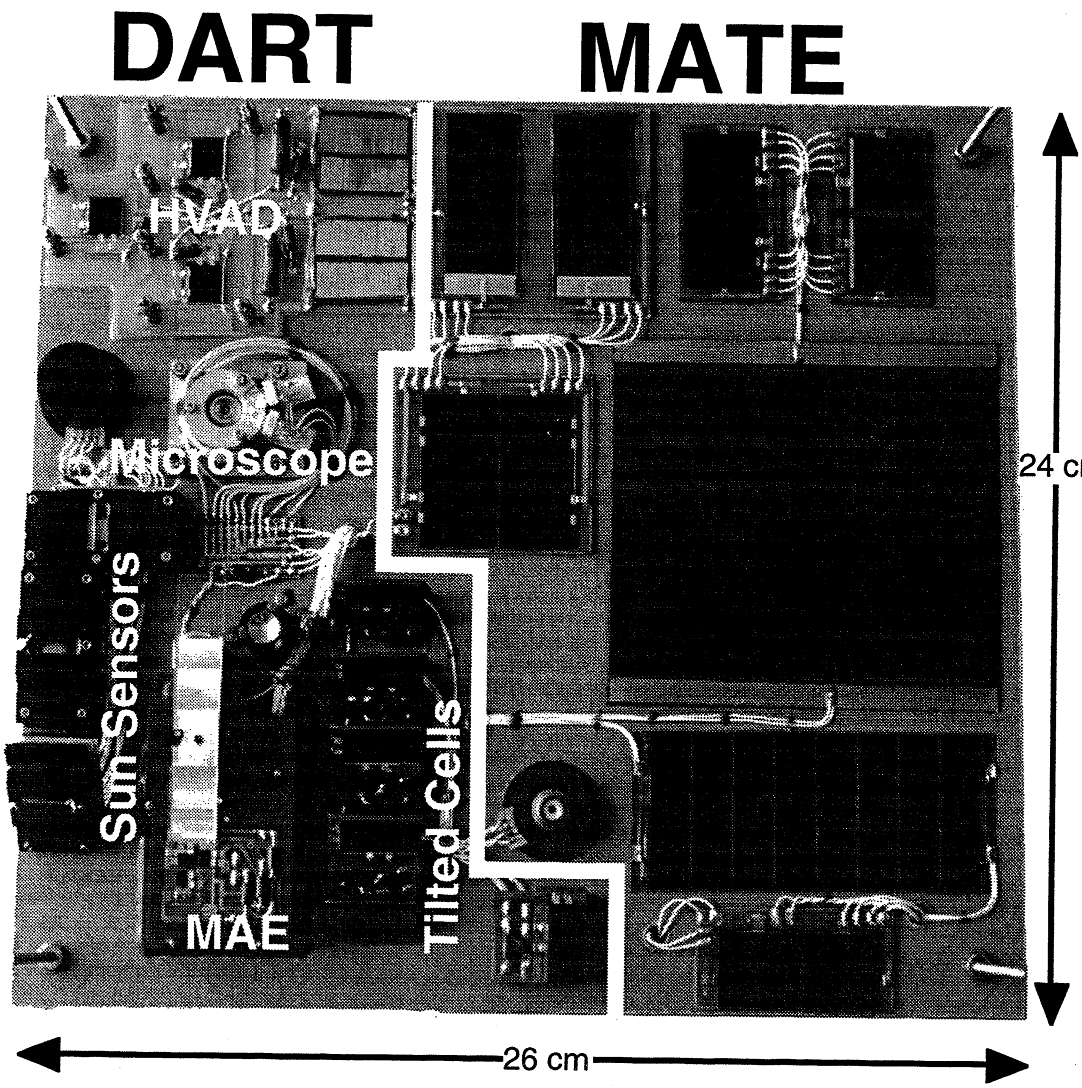

Figure 1) Photograph of the DART and MATE flight hardware.

Dust Microscope

The microscope measures the amount and size of settled dust. It will give the rate of dust deposition, the particle size distribution, the particle opacity, and will image the shape of larger particles. Since detailed information about dust properties is required to design dust mitigation strategies, this is probably the single most important instrument on the DART package. An image from the flight microscope is shown in figure **3**.

The microscope has a transparent, horizontal, glass plate exposed to the Martian environment. The sun or an LED are used as a light source. Dust settling from the atmosphere will land on this plate, which is held at a fixed distance from a 40X objective lens. A turning prism folds the image beam horizontally, passing through a blue filter and finally imaging the dust on to a

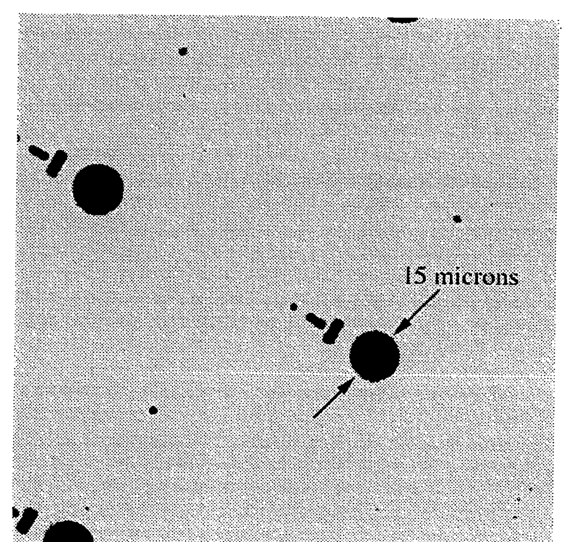

Figure 3) Photograph from the DART flight microscope.

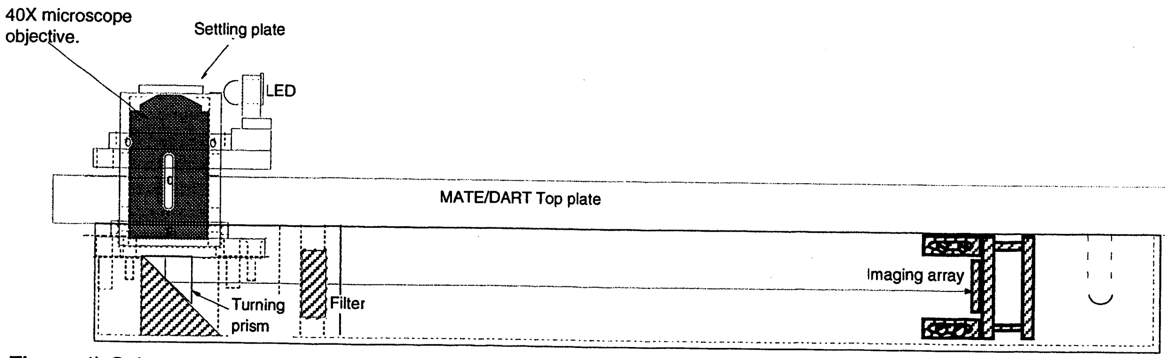

Figure 4) Schematic of the DART microscope.

FUGA-15D active pixel array. It is capable of imaging particles down to roughly 0.5 microns diameter. The entire microscope assembly weighs less than 220 grams. A schematic of the microscope assembly is shown in figure 4.

Material Adherence Experiment (MAE)

The MAE dust coverage monitor is a device to measure the accumulation of dust on the spacecraft (figure **5**). The method of measuring dust is identical to that flown on Pathfinder: dust settles on a transparent plate, and a solar cell measures the intensity of the sunlight through the settling plate. By command, the settling plate can be rotated away from the cell, and the

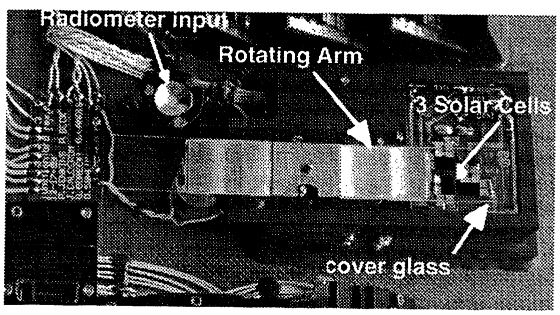

Figure 5) Material adherence experiment.

solar cell measured again. This results in a direct measurement of the optical obscuration [**5**]. By incorporating a GaInP solar cell, a GaAs filtered bottom cell and a single junction GaAs cell under the settling plate, we can observe the effect of dust coverage in different spectral regions. In addition, the opposite end of the rotating arm can swing over the MATE spectral radiometer input optic. Allowing a direct measurement of the transmission spectrum of settled dust.

Sun Position Sensors

The sun position sensors locate the sun's altitude and azimuth relative to the DART top plate. We also intend to use this measurement to obtain a measure of the optical depth of the atmospheric dust. The sun sensors are designed to measure sun position when the sun is within 45 degrees of zenith. A third element measures sun elevation at lower sun angles.

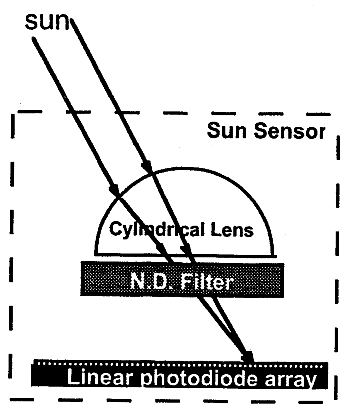

Figure 6) Schematic of a sun sensor.

Each of the three sun position sensors is comprised of a cylindrical lens mounted orthoganally to a 512-element linear photodiode array. The lens focuses the sun onto one element of the photodiode array through a neutral density filter. As the sun tracks across the sky, the sun's image will sweep across different photodiode elements. The angular resolution is approximately 0.3°.

Tilted Cells

Use of a tilted solar array may be the simplest solution to the dust accumulation problem. The Pathfinder experiment measured only dust accumulation on a horizontal surface.

Measurements of the camera window on the Viking lander showed no dust adhering to the vertical surface. Observations of the thermal shell of the Viking landers seemed to show that dust did not build up on the tilted surfaces. Unfortunately, these observations are anecdotal, and no quantitative measurement of accumulation was made. We have decided that a high priority is to verify the conjecture that tilted solar cells will not accumulate dust, and to get an indication of what angle is required to avoid dust coverage.

Single junction GaAs solar cells are tilted at 30°, 45°, and 60°, plus a control (horizontal) cell. One additional cell tilted at 30° has a low friction diamond-like carbon coating. A sketch of the tilted cell experiment is shown in fig. 7.

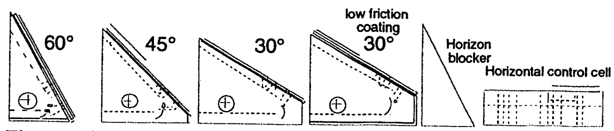

Figure 7) Sketch of the tilted cell experiment.

High Voltage Abatement of Dust (HVAD)

An electrostatic dust removal method will be tested. Electrostatic dust removal is a possible means of dust mitigation with the advantage of requiring no moving parts. Since the Martian dust is most likely charged (due to triboelectric charging and photoionization), a continuous electrostatic field may prevent dust from settling on solar cells. A high-voltage vertical junction photovoltaic array [6] provides an electrostatic potential continuously to the test cells (during daylight operation). The electric field strength in the neighborhood of the cells will be approximately 100 Volts/cm.

Three solar cells will be tested, one with positive potential, one with negative potential, and one solar cell to test whether a transverse electric field can sweep dust away from the cell before it accumulates. Figure 8 shows the electrical schematic. In each case, a wire at a "ground" reference is used as the second electrode. Three GaAs solar cells are fitted with a transparent, conductive (ITO), cover glass. Four vertical multi-junction silicon solar cells are wired to yield ±80V. One cell is biased at +80V and one at –80V. Wires are suspended above and to one side of the cells to establish the direction of the electric field. A third cell has a transverse electric field of 160V.

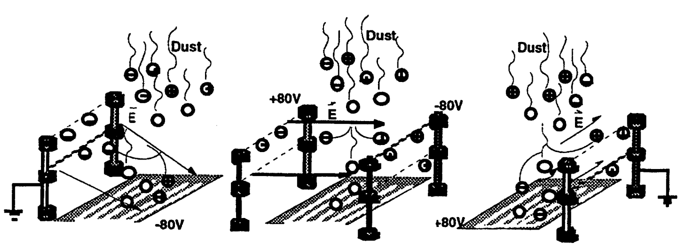

Figure 8) Electrical Schematic of the HVAD experiment.

MISSION STATUS

Qualification testing of all the MIP hardware is nearly complete. The DART experiment delivered flight hardware for MIP in August of 2000. The MIP experiment was originally supposed to fly on the Mars 2001 lander. The 2001 lander mission was cancelled in June of 2000. A future flight opportunity for MIP is uncertain at this time.

ACKNOWEDGEMENTS

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REFERENCES

[1] G.A. Landis and P. Jenkins, "Dust on Mars: Materials Adherence Experiment Results from Mars Pathfinder," *Proceedings of the 26th IEEE Photovoltaic Specialists Conference,* Anaheim CA, pp. 865-869, Sept. 29-Oct. 3 1997.

[2] D. Kaplan, et. al, "The 2001 Mars In-situ-propellant-production Precursor (MIP) Flight Demonstration: Project Objectives and Qualification Test Results," AIAA 2000-5145, SPACE 2000 Conference & Exposition, September 2000.

[3] Geoffrey A. Landis, Phillip P. Jenkins, Cosmo Baraona, David Wilt, Michael Krasowski, and Lawrence Greer, Proceedings of the 2nd World Conference on Photovoltaic Energy Conversion, Vol. III, pp. 3699-3702 (1998).

[4] D. Scheiman, et. al, " Mars Array Technology Experiment", this conference.

[5] P. Jenkins, G. Landis, and L. Oberle, "Materials Adherence Experiment: Technology," paper IECEC-97339, *Proc. 32nd Intersociety Energy Conversion Engineering Conf., Vol. 1,* 728-731, July 27-Aug. 1 1997, Honolulu HI.

[6] B.L. Sater, "Vertical Multijunction Cells for Thermophotovoltaic Conversion," *First NREL Conf. on Thermophotovoltaic Generation of Electricity, AIP Conference Proceedings 321,* pp. 165-176 (1994).