PROGRESS OF THE DUST ACCUMULATION AND REMOVAL TECHNOLOGY EXPERIMENT (DART) FOR THE MARS 2001 LANDER

Phillip Jenkins*, Geoffrey A. Landis*, David Wilt†, Michael Krasowski†, Lawrence Greer†, Cosmo Baraona† and David Scheiman*
* Ohio Aerospace Institute, Cleveland, Ohio 44142
† NASA Glenn Research Center, Cleveland, Ohio 44135

ABSTRACT

Dust deposition could be a significant problem for photovoltaic array operation for long duration missions on the surface of Mars. Measurements made by Pathfinder showed 0.3 percent loss of solar array performance per day due to dust obscuration. We have designed an experiment package, "DART," which is part of the Mars ISPP Precursor (MIP) package, to fly on the Mars-2001 Surveyor Lander. This mission, to launch in April 2001, will arrive on Mars in January 2002. The DART experiment is designed to quantify dust deposition from the Mars atmosphere, measure the properties of settled dust, measure the effect of dust deposition on array performance, and test several methods of clearing dust from solar cells.

INTRODUCTION

The Mars Pathfinder lander and its rover, Sojourner, demonstrated that it is possible to operate a mission on the surface of Mars entirely on solar power [1]. Future missions even more ambitious in scope will require higher power levels and will operate for longer duration on Mars.

Large amounts of dust are raised into the atmosphere of Mars during dust-storms. Atmospheric dust consists of relatively small (micron scale) particles, suspended at altitudes of up to 20 km. The effect of this suspended dust on the insolation reaching the surface of Mars has been calculated by several researchers [2,3].

This dust settles out the atmosphere onto any horizontal surface. Atmospheric dust settling can be visible from Earth in the form of albedo variations visible when dust covers surface rocks after large dust storms. Both the Pathfinder lander and the Sojourner rover measured a progressive loss of solar array power due to deposited dust. The most accurate measurement, by the MAE experiment on the rover, measured an obscuration of the solar arrays due to dust deposition at a rate of 0.3% per day over the first 4 weeks of the mission [4]. This is potentially the major lifetime-limiting factor for a solar-power system on any Mars mission which is required to last for longer than 100 days, unless a technique is developed to periodically remove the dust or prevent settled dust from coating the array.

Atmospheric dust deposition can be considered to consist of two components: the settling of dust after global dust storms, and the settling of the ordinary atmospheric dust always present in the atmosphere [5]. A third component is the dust raised during spacecraft landing or by human or robotic operations on the surface. The worst-case scenario is that the lander must operate during the settling phase of a global dust storm.

Dust obscuration can be catastrophic for a long mission, unless dust removal is effected. It will be necessary to have a means to remove dust if a long-duration stay on the surface is to be achieved. Preferably, the dust removal should require little or no EVA activity by astronauts, since, even for a human mission, a Mars propellant plant will probably be operated as an unmanned vehicle launched two years before the piloted launch. A technique that requires no moving parts and is as simple as just pressing a button would be most desirable. A survey of dust removal techniques on Mars is given by Landis [6].

The utility of dust removal technique on Mars may depend on the detailed properties of the surface dust, including composition, binding strength, particle size distribution, native charge, and surface chemical state. These properties cannot be adequately simulated in an Earth environment, but must be tested with actual Mars dust. It would also be desirable to demonstrate operation in the actual environment, with the temperature, UV radiation, and dry, low-pressure mixed-gas atmosphere (CO_2 plus secondary components of N_2, and Ar) of Mars.

MARS ISPP PRECURSOR (MIP)

The Mars ISPP Precursor (MIP) package is a set of experiments designed to demonstrate on Mars the component technologies required to produce oxygen from Martian atmosphere. The experiment package is scheduled to fly on the Mars-2001 Surveyor lander, to launch in April of 2001. The five experiments comprising MIP will demonstrate production of power by advanced solar-cell technologies, acquisition and compression of carbon dioxide from the Martian atmosphere, conversion of the compressed atmosphere to oxygen by zirconia electrolysis, radiation of waste heat from the compression process to the night sky, and methods of mitigation of the effects of dust on solar arrays. The package will also make measurements of the Mars environment which will be of engineering use and scientific interest.

The Dust Accumulation and Removal Technology (DART) experiment is one of the five experiments of the MIP package. DART will gather engineering data about the deposition rate and properties of the dust and demonstrate the removal of dust. 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 the Mars-2001 Surveyor lander [7].

DART SENSORS

The DART experiment consists of five different instruments shown in schematic in figure 1. The first three listed below support the characterization of Mars dust. The last two instruments are experiments designed to mitigate dust build up on solar cells. During development of DART, silicon solar cells and GaInP cells [8] were used. For flight, either single junction GaAs or GaInP solar cells supplied by Spectrolab are used.

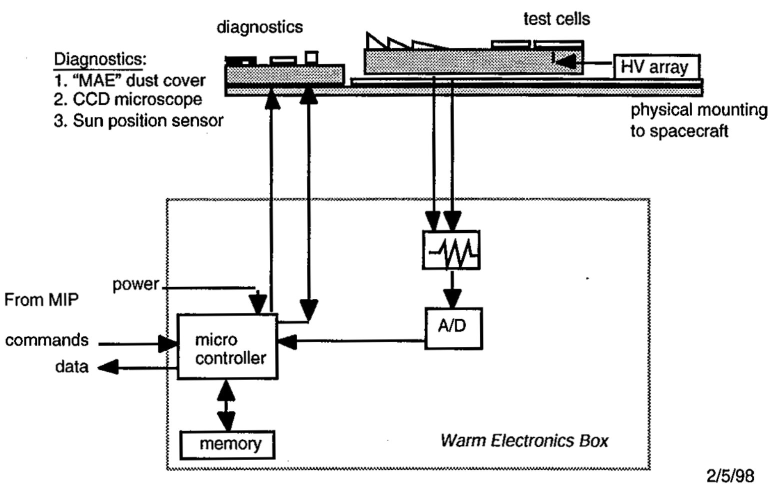

Figure 1: DART experiment package block diagram

Material Adherence Experiment (MAE)

The MAE dust coverage monitor is a device to measure how much dust settling has occurred on the spacecraft. 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 solar cell measured again. This results in a direct measurement of the optical obscuration [9]. By incorporating three solar cells under the settling plate, we can observe the effect of dust coverage in three spectral bands of interest.

The MAE dust coverage monitor is comprised of the following elements:

1. Transparent plate for dust settling
2. Rotary mechanism to move plate
3. A GaInP solar cell, GaAs filtered bottom cell and a single junction GaAs cell.
4. Resistors to measure photodiode current
5. Sensor element to detect position of rotation

Dust Microscope

The microscope measures the amount and properties of settled dust. It will give the rate of dust deposition, the particle size distribution, the particle opacity, and will image the shape of the 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.

The microscope is comprised of the following elements:

1. Settling plate. A transparent, horizontal, glass plate. Dust settling from the atmosphere will land on this plate, which will hold it at a fixed focus distance from the objective.
2. Objective lens. A lens system which magnifies the image of the front surface of the plate. We are anticipating use of a 40x objective, to resolve particles down to roughly half-micron diameter.
3. Turning prism. The turning prism bends the light path by 90 degrees to allow us to mount the microscope horizontally beneath the plate.
4. Focal plane array. The microscope focal plane uses a FUGA-15D active-pixel array.
5. Short-pass filter ("blue filter").
6. Illuminator. A light-emitting diode which illuminates the dust particles.
7. Control electronics
8. Structure. A structural frame holds the components in optical alignment and also excludes stray light.

The microscope is shown schematically in Figure 2.

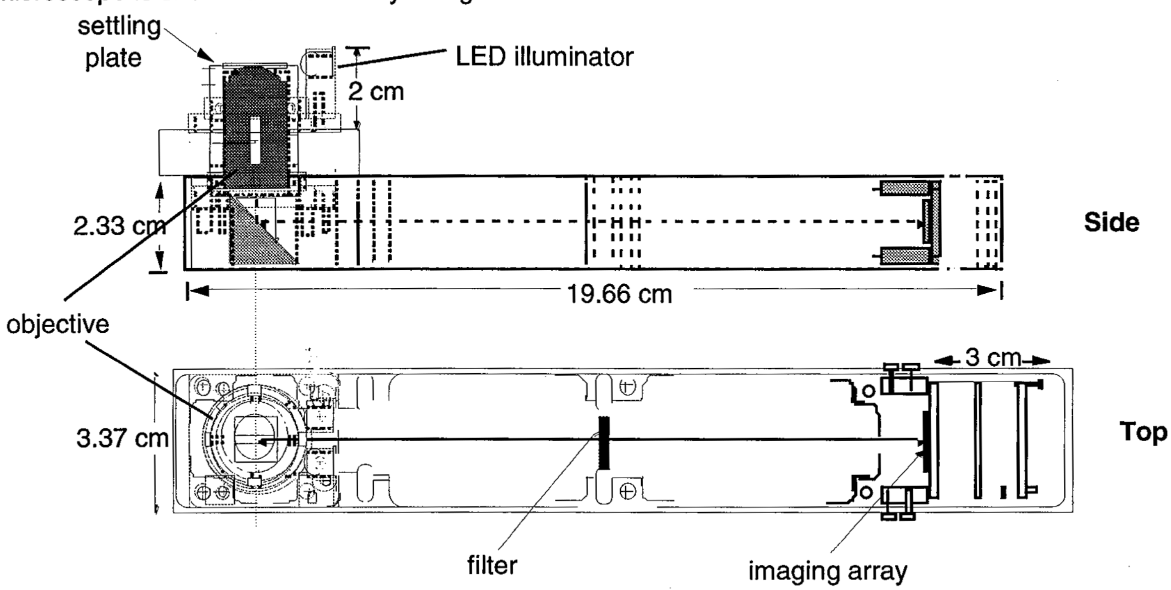

Figure 2: Schematic of microscope to image settled dust. Top: view from the side. Bottom: view from top

Sun position sensor

The sun position sensors locate where the sun is relative to the solar panel. We also intend to use this measurement to obtain a measure of the optical depth of the atmospheric dust (τ). 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.

The sun position sensor is comprised of three each of the following elements, oriented orthogonally:

1. 512 element linear photodiode array
2. Neutral density filter
3. Cylindrical lens
4. Mounting and stray-light shield

Tilted cells

First, we will test whether the dust will deposit onto tilted surfaces. 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 also did not build up on the tilted surfaces. Unfortunately, this observation is anecdotal, and no quantitative measurement of accumulation has been made. Due to this observation, we have decided that a high priority is to verify the conjecture that tilted solar cells do not accumulate dust, and to get an indication of what angle is required to avoid dust coverage.

The following elements comprise the tilted cell measurement:

1. Single junction GaAs Solar cells tilted at 30°, 45°, and 60°, plus a control (horizontal) cell
1a. Solar cell tilted at 30°es with low friction, diamond- like carbon coating
2. Horizon mask
3. Resistors to measure current

Electrostatic Dust Mitigation

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 charge may prevent dust from settling on solar cells. A high-voltage vertical junction photovoltaic array [10] will provide an electrostatic potential continuously to the test cell (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 3 shows the electrical schematic. In each case, a wire at a "ground" reference is used as the second electrode.

The following elements comprise the electrostatic dust mitigation measurement:

1. Three GaAs solar cells, each fitted with a transparent, conductive, cover glass
2. Four vertical multi-junction cells wired to yield ±80V
3. Wires suspended above and to one side of the cells to establish the direction of the electric field.
4. Resistors to measure solar cell current and monitor the high voltage array

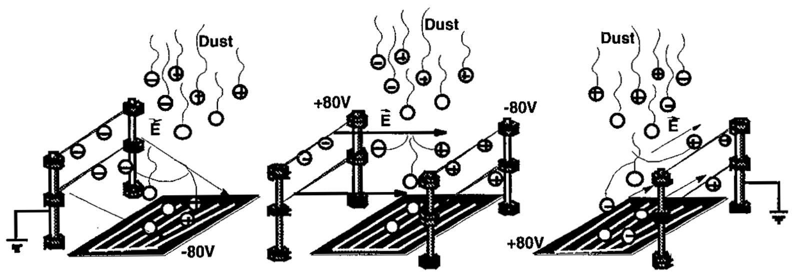

Figure 3: Schematic of electrostatic dust removal.

STATUS

The DART experiment on the Mars-2001 Surveyor Lander mission will measure the deposition rate and properties of Martian dust, and will test two methods for mitigating the effect of dust accumulation on solar arrays. At this time, the Qualification hardware is being built and Flight hardware is scheduled for March 2000 delivery.

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further information can be found on the NASA Lewis PV branch web page, http://powerweb.lerc.nasa.gov/pv

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