NASA Technical Memorandum 102507

Aeolian Removal of Dust From Photovoltaic Surfaces on Mars

James R. Gaier and Marla E. Perez-Davis
Lewis Research Center
Cleveland, Ohio

and

Mark Marabito
Cleveland State University
Cleveland, Ohio

February 1990

NASA

(NASA-TM-102507) AEOLIAN REMOVAL OF DUST FROM PHOTOVOLTAIC SURFACES ON MARS (NASA) 19 p CSCL 10A

N90-19299

Unclas

G3/20 0271128

Aeolian Removal of Dust From Photovoltaic Surfaces on Mars

James R. Gaier and Marla E. Perez-Davis,
NASA Lewis Research Center, Cleveland, OH 44135

Mark Marabito
Cleveland State University, Cleveland, OH 44115

SUMMARY

It is well documented that Mars is totally engulfed in huge dust storms nearly each Martian year. Dust elevated in these global dust storms, or in any of the numerous local dust storms could settle on photovoltaic surfaces and seriously hamper photovoltaic power system performance. Using a recently developed technique to uniformly dust simulated photovoltaic surfaces, samples were subjected to Martian-like winds in an attempt to determine whether natural aeolian processes on Mars would sweep off the settled dust. The effects of wind velocity, angle of attack, height off of the Martian surface, and surface coating material were investigated. Principles which can help to guide the design of photovoltaic arrays bound for the Martian surface were uncovered. Most importantly, arrays mounted with an angle of attack approaching 45° show the most efficient clearing. Although the angular dependence is not sharp, horizontally mounted arrays required significantly higher wind velocities to clear off the dust. From the perspective of dust clearing it appears that the arrays may be erected quite near the ground, but previous studies have suggested that saltation effects can be expected to cause such arrays to be covered by sand if they are set up less than about a meter from the ground. Providing that the surface chemistry of Martian dusts is comparable to our test dust, the materials used for protective coating may be optimized for other considerations such as transparency, and chemical or abrasion resistance. The static threshold velocity is low enough that there are

regions on Mars which experience winds strong enough to clear off a photovoltaic array if it is properly oriented. Turbulence fences proved to be an ineffective strategy to keep dust cleared from the photovoltaic surfaces.

INTRODUCTION

In the past few years there has been a growing consensus that the United States will, perhaps in the next twenty years, send a manned mission to land on the surface of Mars. Because of the length of the journey, even initially astronauts will probably stay on the surface for an extended period of time, perhaps several weeks. During their stay there will be power requirements which will exceed those of present spacecraft[1], and an important component of that power will no doubt be supplied by photovoltaic arrays.

Photovoltaic arrays will be subjected to an environment unlike those in which they have heretofore been used. The atmosphere of Mars consists of CO_2 (95.3 percent), N_2 (2.7 percent), Ar (1.6 percent), O_2 (0.13 percent), CO (0.07 percent), H_2O (0.03 percent), and ppm or less of O_3, Ne, Kr, and Xe[2]. Natural environmental conditions on Mars such as high velocity winds, dust, ultraviolet radiation, rapid temperature changes, soil composition, and atmospheric condensates (H_2O and CO_2) may pose a threat to photovoltaic arrays. Results from the soil analysis experiments on board the Viking landers suggest the presence of highly oxidizing species in the soil[3]. Although 99.9 percent of the wind measurements from the Viking landers showed velocities of 20 m/s or less[4], dust storms were observed to move at higher velocities (up to 32 m/s)[5], and aeolian features (sand dunes, etc.) suggest that on occasion there are very high winds[6], albeit at low pressure (5 - 8 torr). The surface temperatures range from 135 to 300 K[7], and daily temperature swings ranging from 20 to 50 K are not uncommon[8].

One of the possible threats comes from local and/or global dust storms which engulf the planet nearly annually. Infrared spectra from the Mariner 9 spacecraft suggested that the dust is a mixture of many minerals (granite, basalt, basaltic glass, obsidian, quartz, andesite or montmorillonite), and that the average particle size in the atmosphere is about 2 μm.[9] A significant amount of dust may be deposited on the array surface during a dust storm[10] which could occlude the light and significantly degrade the performance of the array. It is not known at this point how serious a problem dust accumulation might be. Will the tenuous but high velocity winds blow the dust off of the array? Perhaps the photovoltaic array can be designed so as to maximize the ability of the array to be self-clearing.

The purpose of this study is to determine how likely it is that the dust will be removed from photovoltaic arrays by natural aeolian processes, and how the shape and orientation of the array can affect this process.

METHODS AND MATERIALS

There are a variety of variables which could effect dust removal from a photovoltaic surface on Mars. In these tests we evaluated the effects of surface coating on the array, angle of attack, wind velocity, height from the planetary surface, and turbulence.

One inch (2.54 cm) square, 5 mil (.13 mm) thick glass coverslips were used for the sample substrates. These were left bare or ion beam sputter deposited with a coating of SiO_2, polytetrafluoroethane (PTFE), 50 percent mixture of SiO_2 and PTFE, indium tin oxide (ITO), or diamond-like carbon (DLC). Table I summarizes the coatings. These coatings were chosen because they are candidate materials for protective coatings for photovoltaic arrays. The substrates were thin, both to present low aerodynamic drag, and for low mass, which was important for accurate weight determinations of the dusted substrates.

The samples were mounted in specially designed sample holders by means of foil tabs which stretched across two corners, and held down by a foil tab attached to a removable pin (see Figure 1). Samples were held at a tilt angle of 0, 22.5, 45, 67.5, or 90 degrees from the floor. The sample holders could also be held horizontally for optical transmittance measurements.

The sample holders were tilted so that the samples were held horizontally, and subjected to a dusting which simulates dust accumulation in the aftermath of a dust storm. The method of dusting and the resulting dust distribution are discussed in detail elsewhere[11].

The dust used in these experiments was 1800 grit optical grinding powder from American Optical Company. It was principally an aluminum oxide powder (89 percent) with significant amounts of silicon dioxide and titanium dioxide (6.6 and 3.0 percent respectively). It also contained a small amount of iron (III) oxide (0.6 percent) and chromium (III) oxide (0.6 percent). The particle size ranged from .1 to 25 μm. It is recognized that the chemistry of the Martian soil, while not known, is probably substantially different from this powder, but the particles which become elevated to altitudes greater than about a meter are probably in this size range. Although the values for dust clearing wind velocities on Mars may differ from those in these simulation experiments, the order of magnitude and the trends in angle and height from the surface are expected to be similar.

Because of size limitations imposed by the dusting apparatus, no more than four sample holders could be dusted at once. The amount of dust which accumulated on the samples was difficult to control, being critically dependent upon the amount of dust in the chamber, the elevation pressure, and the time allowed for larger particles to settle out. For this study 13 dusting runs were required, and the resulting samples had ratios of transmittance of the dusted samples (T_d) to transmittance of the pristine samples (T_o) which were as low as 0.18 and others as high as 0.82. The spatial uniformity of each dusting operation was much lower. The T_d/T_o for each sample is shown in Figure 2.

The winds on Mars was simulated using the Martian Surface Wind Tunnel (MARSWIT) at NASA Ames Research Center. The MARSWIT is a low pressure (down to a few torr) wind tunnel 14 m in length with a 1 by 1.1 by 1.1 m test section located 5 m from the tunnel entrance. This flow-through wind tunnel is located within a 144,000 ft^3 vacuum chamber which was back-filled with CO_2. Its characteristics are described in detail elsewhere[12]. The samples were placed in the MARSWIT and tested under the wind conditions listed in Table II.

The samples were weighed before dusting, after dusting, and after MARSWIT exposure. However, the weight of the dust added to the optical surfaces was below the sensitivity of the balance used (0.1 mg).

Optical transmittance measurements were made by sliding the transmittance measurement device (TMD) over the sample. In the TMD a white light source is suspended above the sample, and the sensing head of a Coherent Model 212 Power Meter is beneath the sample. Absolute transmittance measurements were converted into percent transmittance measurements. Measurements were made before and after the samples were dusted (T_o and T_d respectively), and after the dusted samples were subjected to winds in the MARSWIT (T_f).

The amount of dust which was cleared from the samples was evaluated using a dust clearing parameter, which was defined as the ratio of the transmittance change on wind exposure of the dusted samples (T_f - T_d) to that of the transmittance change upon dusting (T_o - T_d). This function is constrained to vary from zero to one. There is, unfortunately, a dependence of the value of T_d used in different sample dustings on this parameter.

The final transmittance (T_f) is a function of wind velocity, angle to the wind, surface chemistry, particle size, and time. It may also be a function of the amount of dust deposited initially. Assume that the degradation of T_f from T_o arises solely from particles remaining on the surface. For the most part these particles are sufficiently small that surface adhesion is stronger than the forces that can be exerted by the dynamic pressure of the wind. The number of these particles will increase as the total number of particles dusted on the sample increases (that is, as T_d decreases) up until a monolayer is built up. Beyond that there is only particle-particle cohesion. Thus, T_f will be a function of T_d until the monolayer is established, and beyond that it will not. If T_f is a function of T_d then, for dusting runs of low T_d, the dust clearing parameter would take a higher value for the same dust clearance effectiveness. For dusting runs of high T_d, the dust clearing parameter should be independent of T_d.

Winds at two different heights from the floor of the wind tunnel were tested. Samples were placed at about 2.5 cm, which should be within the floor's boundary layer, and at about 50 cm, which should be well above it.

A turbulence fence was constructed to increase the wind turbulence at the sample. It was thought that the turbulent flow might be effective at clearing the dust at wind speeds lower than those in the free stream. It was made up of an vertical array of eight .125 in (3.2 mm) diameter horizontal rods spaced every .375 in (9.5 mm).

RESULTS AND DISCUSSION

The two most important variables to dust clearing efficiency, were found to be the angle of attack, and the velocity of the wind. Accordingly, they will be discussed first, and turbulence and coating material will be discussed as small perturbations on the effects.

Higher wind velocities are expected to clear photovoltaic surfaces more efficiently. It might also be suspected that there will be a threshold value for the wind velocity below which there will be no clearing, and above which, given sufficient time there will be significant, perhaps even total clearing. The static threshold velocity is that velocity at which dust particles leave the surface without impact from upwind particles. There are several factors which will effect the static threshold velocity including particle size, particle shape, and surface chemistry. In these experiments the particle size was chosen to match that which it is believed to become suspended during a global dust storm, but which would settle out under calmer conditions. Particles less than about 1 μm in size will stay suspended for very long periods of time, and those larger than about 50 μm will never be transported far from the site where they first become airborne. The particles used in this experiment mimic the Martian dust size and shape,[11] the surface chemistry of the particles, however, is likely to be quite different from that found on Mars.

According to current thought, the soils on Mars are likely to be basaltic, and are known to be rich in iron oxides[9]. Further, the Viking results infer the possibility of peroxide and superoxides which may be generated by the ultra-violet radiation that constantly bombards the surface[5]. With the present state of knowledge we cannot hope to duplicate whatever exotic surface chemistry might exist in the Martian soil. In addition, the presence of much more water vapor in the Earth environment would change the surface chemistry even if we did know how to simulate Martian soil. The optical polishing powder has been shown to dust the samples evenly with little particle aggregation[11]. Thus, this material is a reasonable starting point for these studies, and that trends in angle, height, turbulence, etc. should still be valid, but the experiments should be repeated with dust of different surface chemistries to evaluate its effect.

Figure 3 shows the dust clearing as a function of angle for various velocities of simulated Martian wind. The amount that some of the data points lie below zero give some indication of the experimental error. There is a clear indication from Figure 3 that the optimum value was near 45°. Samples with an attack angle of zero showed virtually no dust clearing at velocities below about 100 m/s, while those at 45° cleared to about 92 percent of their original transmittance value at wind velocities as low at 35 m/s. Samples held at angles of 22.5° and 67.5° cleared slightly less efficiently than those at 45°. Samples held at 90° showed still less clearing, but more than those held at 0°. This trend was found with velocities varying from 30 to 85 m/s. In the test with a higher velocity (124 m/s) all of the samples were cleared comparably. In the test with a lower velocity (10 m/s) none of the samples cleared appreciably. Note that the time exposed to the wind was not the same in all cases (see Table I), but the angular dependence of the efficiency of dust clearing is not expected to be time dependent.

In one series of samples in 85 m/s wind test, vertical (90°) sample holders were angled at 0°, 30°, 60°, and 90° from the wind around a vertical axis. This should be an equivalent configuration to having samples on 0°, 30°, 60°, and 90° tilts. The angular dependence was indeed consistent with the other experiments (see Fig. 3).

The threshold clearing velocity predicted by Iverson and White is considerably below the measured values[13]. Using the 0° data we find a threshold velocity of somewhat less than 85 m/s, about an order of magnitude higher than predicted. The experimental conditions, however, were not the same as the theoretical assumptions. Iverson and White assumed a layer of spherical particles laying on a bed of similar particles. In the experiment, there was less than a monolayer of non-spherical particles on various substrates. Intuitively, however, one might expect the threshold velocity to be smaller in the experiment because of the smooth substrate.

Given the angular dependence of the dust clearing, one might suspect that the mechanism of detachment would involve the rolling or sliding of dust particles. For the most part, however, this did not appear to be the case. Photomicrographs of the dust layer remaining on dusted glass surfaces subjected to 35 m/s winds at different attack angles showed no directionality to the dust removal. Only on the samples with an attack angle of 22.5° could it be discerned from the photographs the direction of the wind arrival. This was further confirmed by the photograph of a half-round sample subjected to the same conditions. Only as the attack angle became very low was there appreciable streaking. Thus, turbulence at the surface must act to aerodynamically lift the particles out in a direction which is approximately normal to the surface. This view is supported by classical models of Bagnold[14] in which aerodynamic lift plays a key role in particle motion from a surface at the threshold velocity.

Given the cautions above, the static threshold velocity to remove dust particles from the surface was determined. The data taken at 45° is of most interest, because that will give us the minimum static threshold value. In Figure 4 it can be seen that the minimum threshold value was between 30 and 35 m/s. Although this is higher than the average daily maximum wind speed at the Viking landing sites of about 9 m/s[15], it is not uncommon on some parts of the Martian surface[5].

How important is turbulence in the clearing of dust from surfaces? Turbulence was studied from two different sources, boundary-layer turbulence, and artificially induced turbulence. Turbulence will result in a lower mean velocity (and so a lower mean dynamic pressure to move the particles) but it may result in higher local velocities.

Identical samples were run at about 3 cm and about 50 cm from the floor of the MARSWIT. Figure 5 shows the approximate height of the boundary layer (where the velocity becomes the free-stream velocity) at several different velocities and the height of the samples. It can be seen that the lower samples were within the boundary layer, and the upper ones were not. As can be noted from Figure 6, however, there was no appreciable differences between these two heights. In one experiment, in a 55 m/s wind, a sample holder was placed on end so as to fix the samples nearer to the floor. The holder was placed at a 45° angle to maximize the dust clearing. Figure 7 shows that in this extreme case there may have been small boundary layer effects observed, with the lower samples showing slightly less clearing.

Turbulence was also induced by placing a "fence" of cylindrical rods in front of the samples at a wind speed near the threshold. The hope was that the turbulence fence would lower the threshold wind speed, but the fence was found to actually hinder the clearing slightly (see Figure 8).

A wide variety of photovoltaic cell coatings was tested to determine which coatings would be most effective in shedding the dust. Because of the probable differences in surface chemistry between the test material and actual Martian soils this is risky, but perhaps some general surface principles can be determined. Even though there was a wide variety of materials both conducting and insulating, hard and soft, and high and low coefficients of friction, there were only slight differences among the ability of the coatings to shed the dust.

For a each angle of attack (0°, 22.5°, 45°, 67.5°, and 90°) and for the wind velocities of 55, 85, and 124 m/s, each coating was ranked on the basis of dust clearing parameter from highest (1) to lowest (3 or 6, depending on the number of samples). The average ranking over all of the angles at a given wind speed for each of the coatings is shown in Table III. The last column in Table III shows the average ranking for each coating over all of the angles and all of the wind speeds. Although the error is probably large, there may be some validity to the rankings. Glass and SiO_2 have nearly equal scores, as do PTFE and PTFE/SiO_2. ITO was the easiest to clear, and DLC the hardest. Surface adhesion tests are planned to test the validity of the ranking.

CONCLUSIONS

Even in this first preliminary study principles have been found which can help to guide the design of photovoltaic arrays bound for the Martian surface. Most importantly, if an array is to be self-cleaning it should be tilted at an angle approaching 45°. Although there is wide latitude with this requirement, it seems most important that the arrays are not erected horizontally. Most importantly, arrays mounted with an angle of attack approaching 45° show the most efficient clearing. Although the angular dependence is not sharp, horizontally mounted arrays required significantly higher wind velocities to clear off the dust. From the perspective of dust clearing it appears that the arrays may be erected quite near the ground, but saltation can be expected to cover the arrays if they are set up less than about a meter from the ground[16]. Providing that the surface chemistry of Martian dusts is comparable to our test dust, the materials used for protective coating may be optimized for other considerations such as transparency, and chemical or abrasion resistance. Given the same assumption, there are regions on Mars which experience winds strong enough to clear off a photovoltaic array which is properly oriented, though there are other regions where some other clearing technique will have to be employed. Turbulence fences proved to be an ineffective strategy to keep dust cleared from the photovoltaic surfaces.

ACKNOWLEDGEMENTS

The authors would like to thank R. Leach of Arizona State University and the support staff at NASA Ames Research Center for their thought-provoking discussions and essential assistance with the MARSWIT facility. We would like to acknowledge the contributions of S.K. Rutledge of NASA Lewis Research Center, J. Mihelcic of Cleveland State University, and M. Kussmaul of Sverdrup Technologies for their assistance in preparing the optical coatings. J. Tillman and R. Greeley provided us with helpful discussions and expertise on the Martian environment.

REFERENCES

1. R.J. Giudici, "Electrical Power Systems for Mars", The Case for Mars, (1983), pp. 873-87.

2. T.K. Owen, K. Biemann, D.R. Rushneck, J.E. Biller, D.W. Howarth, and A.L. Lefleur, "The Composition of the Atmosphere at the Surface of Mars", J. Geophys. Res. **82** (1977), 4635.

3. H.P. Klein, Icarus **34** (1978) 666-74.
   also R.L. Huguenin, K.J. Miller, and W.S. Harwood, J. Molecular Evolution **14** (1979) pp. 103-32.

4. D. Kaplan, NASA Technical Memorandum 100470 (1988).

5. A.R. Peterfreund and H.H. Kieffer, J. Geophys. Res. **84** (1979), pp. 2853-63.

6. J.B. Pollack, D.S. Colburn, F.L. Flasar, R. Hahn, C.E. Carlston, and D. Pidek, J. Geophys. Res. **84** (1979) pp.2929-45.

7. H.H. Kieffer, T.Z. Martin, A.R. Peterfreund, B.M. Jakosky, E.D. Miner, and F.D. Palluconi, J. Geophys. Res. **82**, (1977) pp. 4249-91.

8. J.E. Tillman, The Case for Mars II, Vol 62, Science and Technology (American Astronautical Society, 1985) pp. 333-42.

9. O.B. Toon, J.B. Pollack, and C. Sagan, "Physical Properties of the Particles Composing the Martian Dust Storm of 1971-1972", Icarus **30** (1977).

10. R.E. Arvidson, E.A. Guinness, H.J. Moore, J. Tillman, and S.D. Wall, Science **222** (1983) pp. 463-8.

11. M.E. Perez-Davis, J.R. Gaier, R. Kress, and J. Grimalda (1989) *manuscript in preparation.*

12. R. Greeley, B.R. White, J.B. Pollack, J.D. Iverson, and R.N. Leach, NASA Technical Memorandum 78423 (1977).

13. J.D. Iverson and B.R. White, Sedimentology **29**, (1982), pp. 111-9.

14. R.A. Bagnold, Philos. Trans. Royal Soc., Ser. A, **249**, (1956) pp. 239-97.

15. J.B. Pollack, C.B. Leovy, Y.H. Mintz, and W. Van Camp, Geophys. Res. Let. **3** 1976) p. 479.

16. R. Greeley and J.D. Iverson, Wind as a Geological Process on Earth, Mars, Venus and Titan, (Cambridge University Press, 1985).

Table I -- Photovoltaic Array Coatings Tested

Coating	Thickness	Deposition	Substrate
none	-------	-------	glass
SiO_2	650 Å	ion beam	glass
PTFE	≈1000 Å	ion beam	glass
50% PTFE/SiO_2	≈1000 Å	ion beam	glass
ITO	≈1000 Å	ion beam	glass
DLC	≈1000 Å	ion beam	glass

Table II -- Wind Conditions Within the MARSWIT

Velocity	Pressure	Dynamic Pressure	Temperature	Time
10 m/s	7.6 torr	1.8 Pa	290 K	10.0 min
23	7.6	9.8	290	10.0
30	7.6	16.6	290	10.0
31	7.6	17.7	290	15.0
35	7.6	22.6	290	5.0
55	7.6	55.8	290	2.0
85	7.6	134.	290	.50
124	7.6	283.	290	.75

Table III -- Relative Ease of Dust Clearence From Photovotaic Coatings

Coating	55 m/s	85 m/s	124 m/s	Overall
ITO	1.0	1.6	2.5	1.9
PTFE/SiO_2	1.0	1.8	3.0	2.2
PTFE	2.0	2.3	2.3	2.3
SiO_2	3.0	1.9	3.6	2.8
Glass	2.0	2.4	3.8	2.9
DLC	3.0	2.1	4.3	3.2

ORIGINAL PAGE IS
OF POOR QUALITY

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

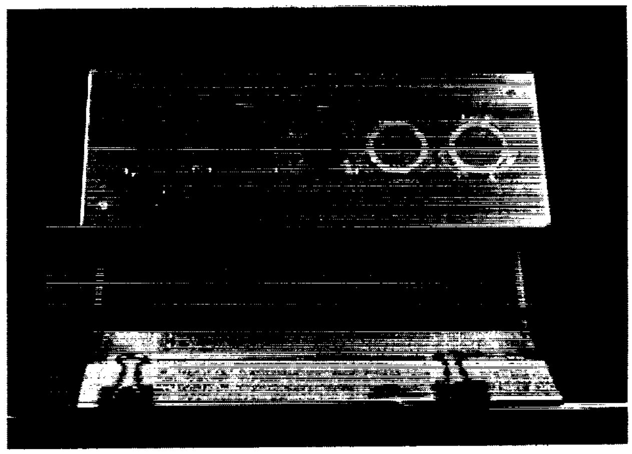


Figure 1. - Sample holder designed to test aeolian dust removal from photovoltaic surfaces.

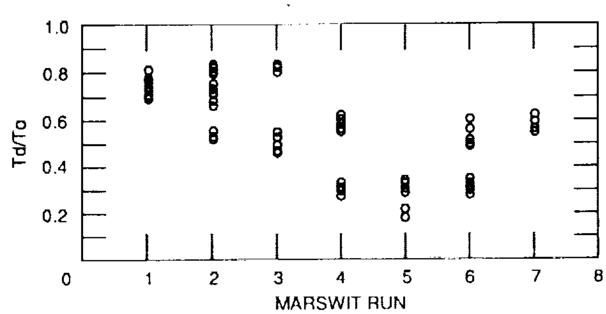
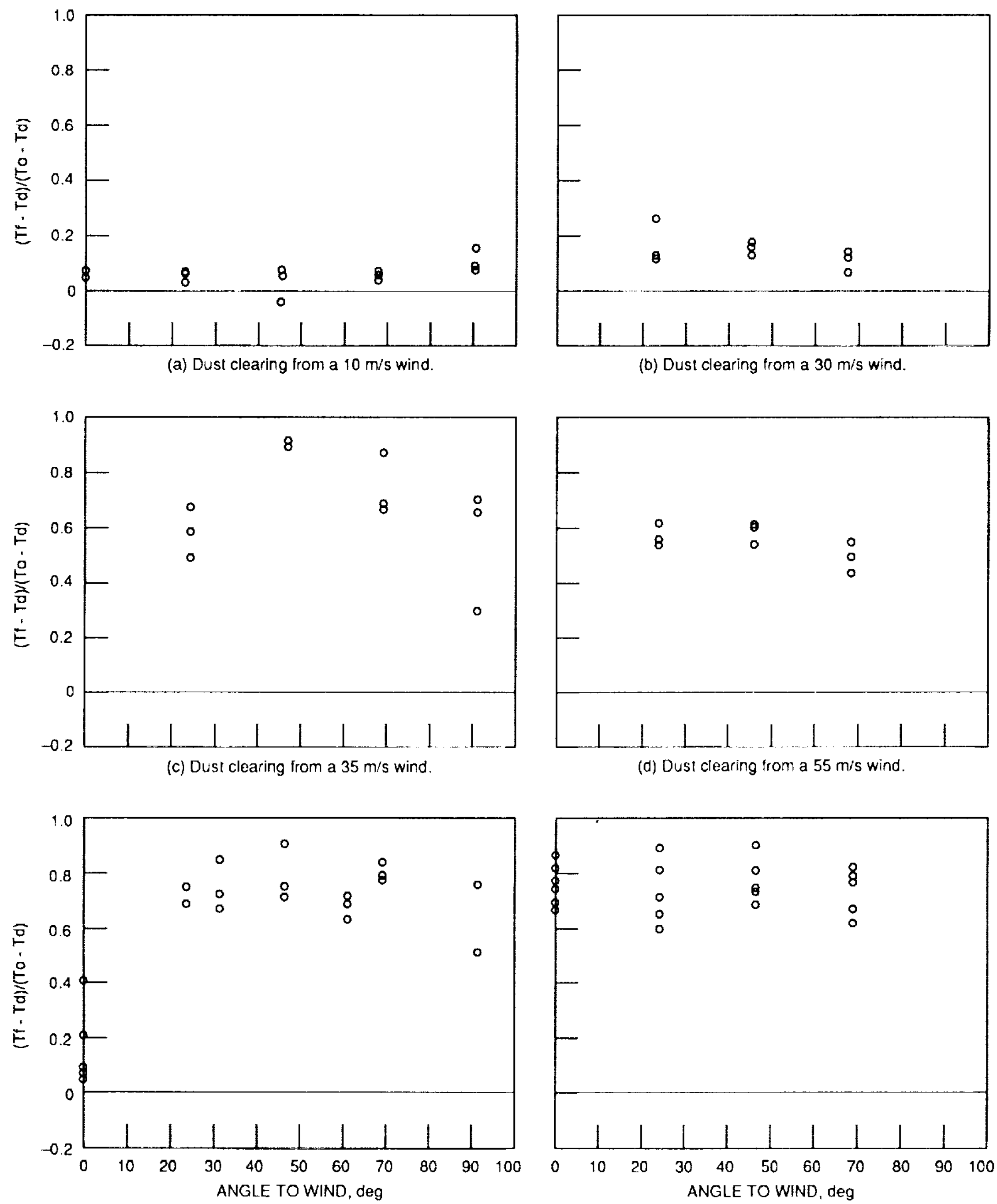


Figure 2. - Uniformity of dust deposition each MARSWIT run.

ORIGINAL PAGE IS
OF POOR QUALITY



(a) Dust clearing from a 10 m/s wind.

(b) Dust clearing from a 30 m/s wind.

(c) Dust clearing from a 35 m/s wind.

(d) Dust clearing from a 55 m/s wind.

(e) Dust clearing from a 85 m/s wind.

(f) Dust clearing from a 124 m/s wind.

Figure 3. - Dust clearing as a function of angle for several different martian wind speeds.

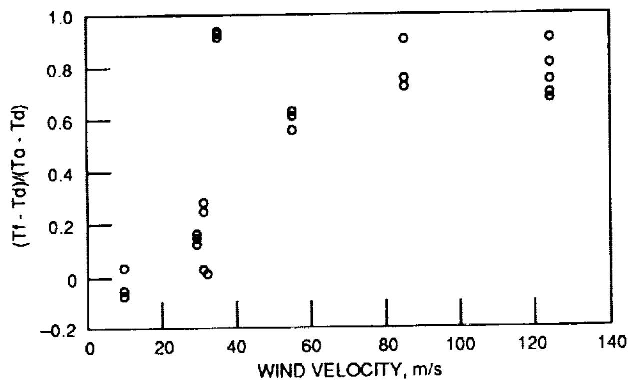


Figure 4. - Dust clearing from a smooth 45° angle surface.

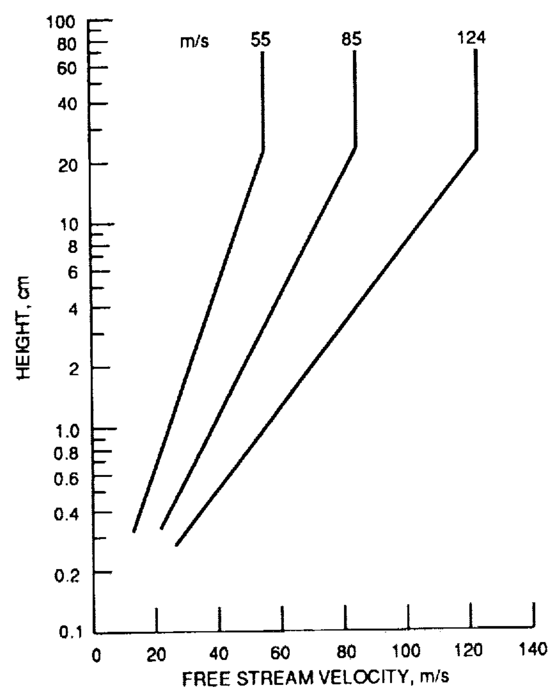


Figure 5. - Nominal boundary layer profiles.

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-102507		

4. Title and Subtitle	5. Report Date
Aeolian Removal of Dust From Photovoltaic Surfaces on Mars	February 1990
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
James R. Gaier, Marla E. Perez-Davis, and Mark Marabito	E-5309
	10. Work Unit No. 591-14-41
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191	11. Contract or Grant No.
	13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546-0001	14. Sponsoring Agency Code

15. Supplementary Notes

James R. Gaier and Marla E. Perez-Davis, NASA Lewis Research Center; Mark Marabito, Cleveland State University, Cleveland, Ohio 44115.

16. Abstract

It is well documented that Mars is totally engulfed in huge dust storms nearly each Martian year. Dust elevated in these global dust storms, or in any of the numerous local dust storms could settle on photovoltaic surfaces and seriously hamper photovoltaic power system performance. Using a recently developed technique to uniformly dust simulated photovoltaic surfaces, samples were subjected to Martian-like winds in an attempt to determine whether natural aeolian processes on Mars would sweep off the settled dust. The effects of wind velocity, angle of attack, height off of the Martian surface, and surface coating material were investigated. Principles which can help to guide the design of photovoltaic arrays bound for the Martian surface were uncovered. Most importantly, arrays mounted with an angle of attack approaching 45° show the most efficient clearing. Although the angular dependence is not sharp, horizontally mounted arrays required significantly higher wind velocities to clear off the dust. From the perspective of dust clearing it appears that the arrays may be erected quite near the ground, but previous studies have suggested that saltation effects can be expected to cause such arrays to be covered by sand if they are set up less than about a meter from the ground. Providing that the surface chemistry of Martian dusts is comparable to our test dust, the materials used for protective coating may be optimized for other considerations such as transparency, and chemical or abrasion resistance. The static threshold velocity is low enough that there are regions on Mars which experience winds strong enough to clear off a photovoltaic array if it is properly oriented. Turbulence fences proved to be an ineffective strategy to keep dust cleared from the photovoltaic surfaces.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Mars; Dust; Dust removal; Photovoltaic surfaces; Durability	Unclassified – Unlimited Subject Category 20

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
Unclassified	Unclassified	18	A03

NASA FORM 1626 OCT 86 *For sale by the National Technical Information Service, Springfield, Virginia 22161

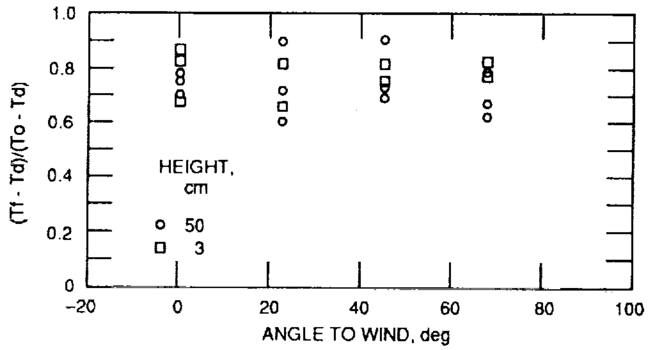


Figure 6. - Dust clearing at different heights from wind tunnel floor.

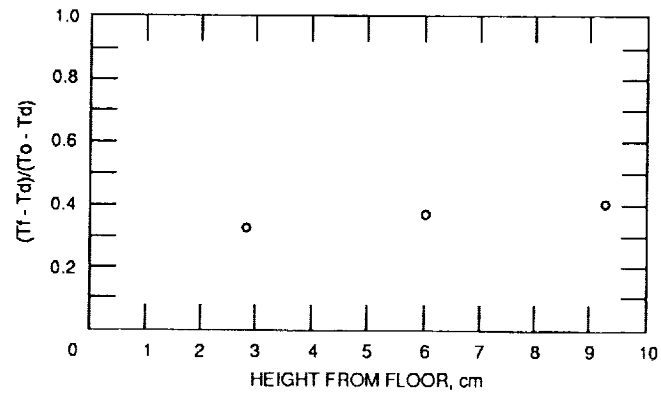


Figure 7. - Dust clearing in boundary layer at 55 m/s.

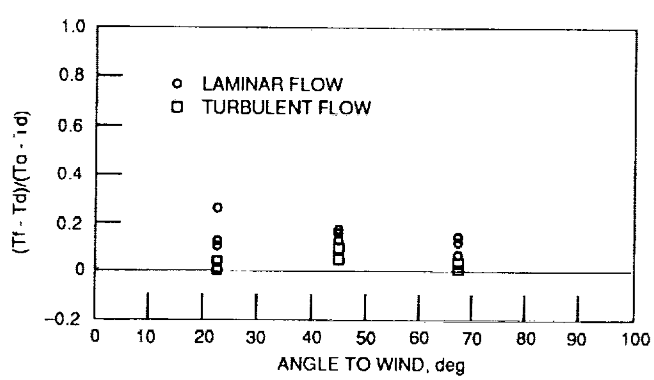


Figure 8. - Dust clearing from a 30 m/s wind.