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MARS: WIND FRICTION SPEEDS FOR PARTICLE MOVEMENT

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Abstract. Wind friction threshold speeds (V_{*t}) for particle movement were determined in a low pressure boundary layer wind tunnel at an atmospheric pressure of 5.3 mb. The results imply that for comparable pressures on Mars, the minimum V_{*t} is about 2.5 m/sec, which would require free-stream winds of 50 to 135 m/sec, depending on the character of the surface and the atmospheric conditions. The corresponding wind speeds at the height of the Viking lander meteorology instrument would be about a factor of two less than the free stream wind speed. The particle size most easily moved by winds on Mars is about 160 μm; particles both larger and smaller than this (at least down to about 5 μm) require stronger winds to initiate movement. The results presented here are in general agreement with previously reported values of V_{*t} for particles 12 μm to 300 μm derived from one atmosphere tests, but are inconsistent with values for particles larger than about 300 μm.

Introduction

Earth-based observations of dust storms on Mars and results from Mariner 9 have shown that eolian activity is an important surface-modifying process on Mars and have prompted interest in the nature of wind-blown particles. Interest in eolian processes is heightened by the Viking mission that will place two spacecraft in orbit and two landers on Mars this summer. Knowledge of the physics of particle movement in the martian environment is required to understand the generation of dust storms, rates of erosion and deposition, and other geological processes.

This report presents preliminary results of wind tunnel simulations of particle movement under near-martian conditions.

Winds transport particles by saltation (bouncing grains), surface creep, and suspension. Particles on Earth are most easily moved by saltation, with both surface creep and suspension resulting primarily from the impact of saltating grains; thus, most research has concentrated on the conditions (wind speeds, etc.) needed to initiate saltation. Results typically are presented as "threshold" curves that relate threshold friction velocity to the diameter of the particle. The threshold friction velocity (V_{*t}) of a particle is the friction speed (V_*) needed to initiate grain movement. $V_* = \sqrt{\tau/\rho}$ where τ is the surface shear stress and ρ is the fluid density. V_* is directly proportional to the wind speed for a neutral adiabatic atmosphere; at an ambient pressure of 5 mb, the free stream velocity is about 17 times the friction speed in the wind tunnel.

On Earth there is an optimum grain size for movement by minimum winds, with stronger winds needed for movement of both larger and smaller grains. The reason for the "upturn" in the threshold curve (fig. 1) for the smaller grains is poorly known, but appears to be related primarily to interparticle forces (e.g., cohesion), as well as aerodynamic effects (Iversen et al., 1976).

Nearly all predictions of martian threshold friction speeds (Sagan and Pollack, 1969, Arvidson, 1972, Greeley et al., 1974, and others) are based on wind tunnel experiments conducted at

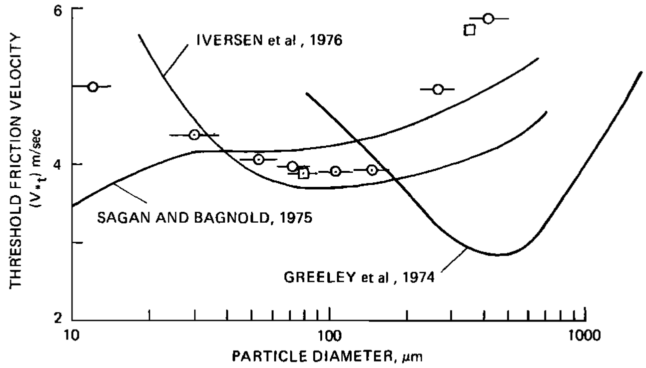

Figure 1. Threshold friction velocities obtained in the wind tunnel at an atmospheric pressure of 5.3 mb for walnut shell particles (white circles; size range indicated by bars). Black symbols indicate samples that were run in a dried state; squares indicate samples of mixed sizes. Also shown is the threshold curve of Iversen et al. (1976), based on 1 bar wind tunnel experiments extrapolating the low pressure conditions and taking into account interparticle forces and lift coefficients; the curve of Greeley et al. (1974) does not take these parameters into account.

1 bar and extrapolated to the martian environment. The most important parameter in the extrapolation is atmospheric pressure -- the low pressures on Mars (~1 to 10 mb) require substantially stronger winds to move particles than on Earth. The basic physics of wind-blown particles is presented in the classic work by Bagnold (1941), but the relative importance of individual parameters such as lift coefficients and cohesion is poorly known. Yet, an understanding of these parameters is critical for extrapolations to Mars. Although some experiments have been conducted at 1 bar which take these parameters into account (Iversen et al., 1976), current extrapolations to Mars produce widely divergent results because of uncertainties in knowledge of forces on small particles at low pressure.

Wind Tunnel Simulations

Because of the uncertainties in particle movement on Mars, a low pressure wind tunnel was established at NASA-Ames Research Center in which threshold experiments can be conducted under conditions approximating those of Mars except for the differences in gravity and atmospheric composition. Experiments were run by placing a patch of grains in the tunnel test section and, under the desired atmospheric pressure (5.3 mb for the nominal Mars case), the wind velocity slowly increased until grain threshold was observed. The criteria for determining threshold follow those of Bagnold (1941); threshold is defined as the movement of particles over the entire bed, rather than the movement of only a few individual particles. The value of the measured free stream wind velocity at threshold was then correlated with the boundary layer profile to obtain a threshold friction speed for the particle tested (Greeley et al., 1974).

Materials used in the threshold tests and their characteristics are shown in Table 1. Although there is no single material that satisfies all test parameters for simulating Mars, this suite of samples is considered a suitable "first estimate," based on the following rationale: Gravity on Mars is 0.38 that of Earth, which results in less force required to initiate particle movement. For tests conducted on Earth to simulate Mars, grains 0.38 as dense as those expected on Mars should be used to offset the difference in gravity. Given the known geological environment on Mars, wind blown particles with specific gravities of 2.6 to 3.0 are reasonable; for threshold simulations on Earth, the corresponding material specific gravities should be ~1.0 to 1.2. Walnut shells were selected as appropriate particles for the primary series of tests because they have a specific gravity of 1.1, can be ground and sorted into different sizes, and the particles have about the same angular shape as natural eolian material (sand and loess). Because the shape of the ground walnut shells is comparable to natural aeolian material, the lift and drag coefficients should also be comparable.

An important factor in particle threshold is the effect of cohesion from adsorbed moisture and from other surface forces. This effect increases with smaller particles since the surface area-to-mass ratio increases. To determine if cohesion from moisture is the primary cause for the "upturn" in the threshold curve for small particles and to assess the effect at low pressure, several particle tests were conducted in which the samples were dried by heating and then tested in the tunnel. The test bed of the tunnel was heated to the temperature that kept the sample dry but did not affect the boundary layer.

Because not all parameters involved in martian eolian processes can be simulated in wind tunnel tests on Earth, it is necessary to use a combination of theory and wind tunnel results for extrapolation to Mars. Before the extrapolation is made, however, as much of the theory as possible should be tested. The expressions derived by

TABLE 1
MATERIALS USED FOR THRESHOLD TESTS

MATERIAL	SPECIFIC GRAVITY	SIZE RANGE, μm	SHAPE
Walnut shell	1.1	20-700	angular
Calcium carbonate	2.7	20-500	subrhombohedral
Glass microspheres	2.7	40-300	spherical
Talc	3.0	5- 20	angular to platy

Iversen et al., (1976) for extrapolation to Mars take into account interparticle forces, surface roughness, lift coefficients, and other parameters, but are based on wind tunnel tests performed at 1 bar and contain uncertainties as to the behavior of particles under low pressure. These expressions were tested against the wind tunnel experiments performed at 5.3 mb (fig. 1) and found to be in good agreement, particularly in the critical particle size range of 30 to 200 μm. The cause of the divergence of the test results and the theory for large particles, however, is unresolved. Future experiments will focus on both larger and smaller particles than those used in these experiments.

Results and Conclusions

Figure 1 shows threshold results performed at low pressure, but with Earth air; figure 2 shows threshold wind friction velocities for four atmospheric pressures, demonstrating the dependence of threshold on pressure. Figure 3 is an extrapolation of the wind tunnel results to Mars based on the results of Iversen et al. (1976) using the appropriate values for kinematic viscosity and density for the martian atmosphere. Several results are significant for Mars:

1. Minimum threshold friction speed. For a nominal martian surface pressure of 5 mb, the minimum V_{*t} is about 2.5 m/sec. Using the expressions for martian atmospheric conditions (Pollack et al., 1976a) for a flat, smooth surface composed of loose particles, this corresponds to a free stream (above the boundary layer) velocity of about 125 m/sec. Corresponding wind speeds at the height of the Viking meteorology instrument would be about half the free stream wind speed. These values could be substantially lower, however, depending on the nature of the surface. For example, if large non-erodible elements such as cobbles are present, then the same V_{*t} could be generated by winds one third to one half that given above (fig. 3). These minimum free stream winds are significantly higher than typical speeds on Mars obtained from general circulation calculations; however, such winds are predicted to occur occasionally (Pollack et al., 1976b).

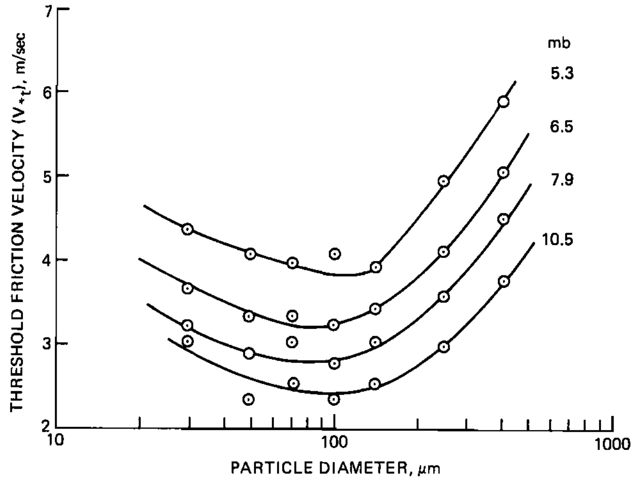

Figure 2. Threshold curves for particles obtained in the wind tunnel for four pressures, showing the dependence of threshold velocities on pressure.

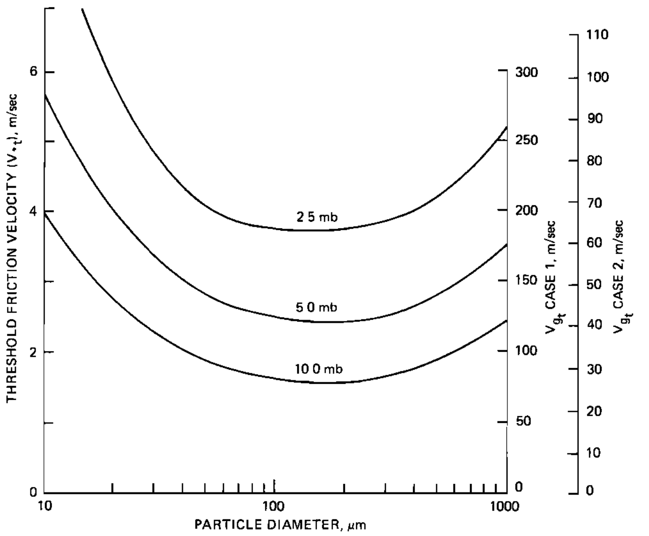

Figure 3. Martian particle threshold curves as a function of particle size at three pressures. Scale on left is V_{*t} in cm/sec, two scales on right are equivalent free stream (above the boundary layer) wind velocities (V_{gt}) based on atmospheric models by Pollack et al. (1976); Case 1 is for winds blowing over a flat smooth surface composed of erodible grains, Case 2 is for a surface containing cobbles and small boulders.

2. Small particle threshold. Sagan and Bagnold (1975) recently extrapolated particle threshold velocities to Mars based on experiments of cohesion-free particle transport. They suggested that particle cohesion due to impact vitrification, vacuum sintering, and adsorbed thin films of water might be absent on Mars, and that small particles (~1 μm) might be more easily moved than 100 μm particles. Low pressure wind tunnel results performed with dried samples and in the absence of impact vitrification and vacuum sintering still show an "upturn" in the threshold curve for small particles (fig. 1). Thus, if grain movement is observed on the martian surface, minimum V_{*t} at 5 mb is 2.5 m/sec and wind speeds near the surface on the order of 25 to 75 m/sec should be expected. These estimates are based on particle threshold taking place on a flat surface; local topography such as raised-rim craters could initiate threshold at lower wind speeds as a result of local vorticies, as discussed by Greeley et. al. (1974).

3. Optimum particle size. The particle size most easily moved (at a minimum V_{*t}) on Mars appears to be about 160 μm (fig. 3) or nearly twice as large as the optimum particle size on Earth. When saltation begins, both larger and smaller particles will be set into motion.

The values of threshold speeds presented here represent the first series of experiments performed in a large, low pressure, boundary layer wind tunnel and should be regarded as preliminary. Further refinements of the threshold curve and extension to both smaller and larger particles are in progress.

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