DETERMINING THE MINIMUM SALTATION GRAIN SIZE ON MARS. R. Sullivan[1], D. Banfield[1], L. R. Collins[1], J. T. Heineck[2], D. T. Korda[1], [1]Cornell University, Ithaca, NY 14853, [2]NASA-Ames Research Center, Moffett Field, CA 94035.

Introduction: Wind-blown grains move primarily through *saltation* or *suspension*. *Saltation* is the wind-driven bouncing of grains across the surface. *Suspension* involves longer, more erratic trajectories where drag from turbulent eddies overwhelms gravitational forces that would otherwise cause grains to fall back to the surface. Generally, coarser particles are likely to saltate, forming ripples and dunes; finer particles are more likely to be suspended into dust storms. Understanding the combinations of wind conditions and grain characteristics leading either to saltation or to suspension is fundamental to understanding aeolian processes on Mars and how these currently dominate surface modification of the planet.

From terrestrial studies, the transition between saltation and suspension is predicted by a ratio, sometimes called the Rouse number, that compares the turbulent eddy wind speeds against the terminal fall speed of entrained grains. Where this ratio is equal to unity (i.e. the contending influences are about equal), particles are in transition between saltation and suspension. Previous work applied the same physics to Mars, leading to long-standing predictions that the smallest particles capable of saltation would be >200 μm—four times larger than on Earth [1-3]. However, evidence from MER *Opportunity* does not support these predictions: Well-formed, active ripples of ~100 μm basaltic sand have been observed [4], for which the Rouse number would be only ~0.5. The failure of the Rouse number on Mars indicates there are shortcomings in this dimensionless parameter to fully describe universal saltation/suspension transitions.

Hypothesis Tested: We have suggested that particle response time vs. timescale of eddy forces on the grain can explain the saltation/suspension discrepancy on Mars not accounted for by the Rouse number [5]. In this concept, particle suspension can occur only if the particle's drag response time is less than both (1) the period of the dominant turbulent eddy size, and (2) the particle's advection time with the passing eddy. If both conditions are not met, the particle is likely to follow a more ballistic trajectory and travel in saltation regardless of the Rouse number [5]. Compared with Earth, on Mars the much lower atmospheric density (factor of 80) and ~25% lower atmospheric dynamic viscosity should lengthen the particle response lag to accelerations applied by turbulent eddies, making the grain less responsive to turbulent lifting forces. As well, mobilized particles injected at low horizontal speed from the ground into the boundary layer will encounter relatively higher wind speeds than on Earth and correspondingly shorter encounter times with turbulent eddies advecting past, before gravity forces the particle back to the surface. Thus, for a given grain size, higher wind speeds on Mars should be required to counteract both effects to achieve the same probability of suspension as on Earth. In this scenario, the transition from saltation to suspension on Mars is delayed by lower density and viscosity to greater turbulent energies and smaller particle sizes than the Rouse Number alone would suggest. We have evaluated our hypothesis with numerical and wind tunnel experiments, at terrestrial and martian atmospheric pressures, and find that results so far support this concept.

Direct Numerical Simulations: (D. Korda lead) Numerical experiments of grain motion were carried out in which the Navier-Stokes equations for the fluid were solved continuously and in three dimensions, allowing turbulent fluid motions—including, specifically, the effects of transient turbulent eddies—to affect drag and acceleration of a grain according to grain size, Earth or Mars atmosphere properties, and Earth or Mars gravity. Wind profiles and turbulence were defined by wind friction speeds exceeding grain threshold-of-motion by 20%. During experiments, grains were inserted within the boundary layer of the simulated wind tunnel environment, and then subsequently were accelerated by turbulent flow and gravity. Scatter in the grain trajectory end point in multiple repeated experiments was used as a measure of how much the turbulent eddies affected trajectories of a given grain size. Increased scatter correlates with trajectories closer to suspension. As expected, under Earth conditions, trajectory scatter began to increase rapidly at Rouse numbers of ~1 (i.e., silicate grains 50-70 μm in diameter being blown by winds 20% stronger than their threshold-of-motion friction speed). Corresponding experiments for Mars showed a similar transition in grain behavior, but at a lower Rouse number, therefore indicating a shift of the saltation/suspension transition to smaller grain sizes than the Rouse number alone would indicate [6]. See Fig. 1. These numerical experiments, limited for practical reasons to within boundary-layer heights of ≤2 cm, identify qualitative trends, but are insufficient to accurately project likely Rouse numbers on Mars in the more complex case of grains saltating at more representative heights >2 cm.

Wind Tunnel Experiments: (J. T. Heineck lead) We used Particle Imaging Velocimetry (PIV) to track wind-blown grains in a wind tunnel at the Planetary Aeolian Laboratory at NASA-Ames. The turbulent boundary layer was ~14 cm thick above the wind tunnel floor. Particles (glass spheres either 35, 71, 119, or 203 μm, depending on experiment) were launched vertically upward into the boundary layer through a slit in the wind tunnel floor, and were then accelerated downwind by fluid drag. Grain movements tracked with PIV were compared with PIV-tracked smoke particles under the same flow conditions to evaluate the degree to which grains of different sizes behaved like saltating or suspended particles. The standard deviation of the grain or smoke cross-flow velocity was used as a measure of saltation (low std. dev.) vs. suspension (high std. dev.). Experiments were conducted at atmospheric pressure and martian pressure (air at ~9 torr). Fig. 2 shows preliminary results. So far, it is clear that: (1) Grains near the 200 μm size that previous work indicated was the saltation/suspension transition in fact behave as saltating particles (not shown). (2) Grains near the ~100 μm size in active aeolian ripples at Meridiani Planum behave much more like saltating particles than suspended particles. (3) Even the smallest (35 μm) grains respond much more sluggishly to turbulent eddies than suspended smoke particles.

Numerical simulations of launched grains: (R. Sullivan lead). These experiments, carried out originally to evaluate kinetic energy of saltating grains, also yielded insights into the saltation/suspension transition size on Mars. These simulations included slip corrections [e.g., 7] that become important at small Knudsen numbers. Unlike the DNS experiments, these simulations did not include turbulence of any kind, but a logarithmic wind profile representing an average speed as a function of height (friction speed 0.6 m/s for Earth, 3.8 m/s for Mars). The absence of transient turbulent eddies in these experiments allowed probing for the minimal grain size for saltation, free from any transient lifting effects of turbulent eddies. Grains were launched at 50° angles at whatever speeds were needed to reach one of several comparative reference heights under various wind conditions. In both Earth and Mars environments, grains as small as 30 μm generally required launch speeds much larger than their impact speeds, inconsistent with sustained saltation. Instead, short-term suspension is more likely (as is observed for 30 μm grains on Earth), indicating that the saltation/suspension transition on Mars is likely to be around 20-70 μm (depending on wind conditions). This is not greatly dissimilar from the saltation/suspension transition size range on Earth.

Conclusions: DNS simulations show that the saltation/suspension transition on Mars is delayed to lower Rouse numbers compared with Earth. Wind tunnel experiments show grains much finer than predicted by earlier work behave as saltating, not suspended, particles. Grains similar to those composing ripples at Meridiani Planum behaved much more like saltating grains than suspended dust. Finally, numerical saltation trajectory simulations in the absence of turbulence suggest that non-turbulent ratios of grain launch speed to impact speed constrain the saltation/suspension transition size for Mars to be around 20-70 μm.

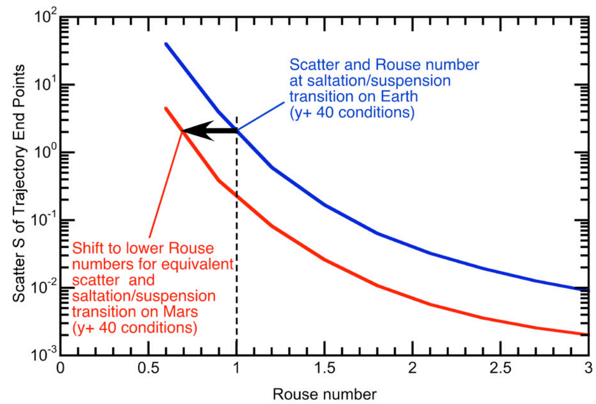

Fig. 1. Shift to lower Rouse numbers on Mars to achieve equivalent saltation/suspension trajectory scattering as on Earth.

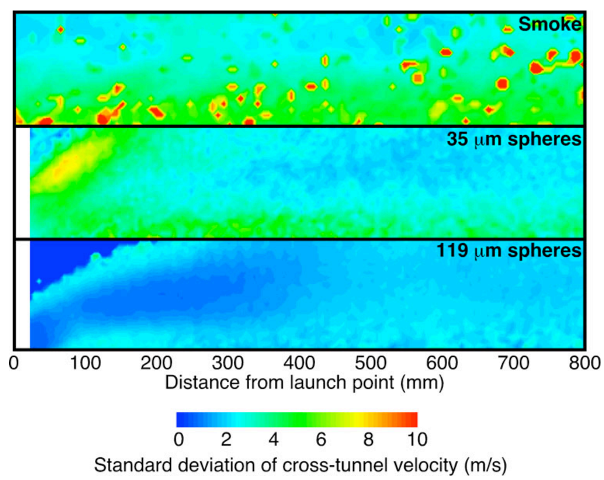

Fig. 2. PIV views of smoke, 35 μm, and 119 μm cross-tunnel velocity standard deviations. Each view is ~160 mm high.

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