Dust devils in the laboratory: Effects of surface roughness on vortex parameters

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Introduction: Laboratory experiments investigating dust devil dynamics were conducted to examine the effect of surface roughness elements on vortex parameters such as core size, tangential velocity, and magnitude of the core low-pressure zone. Natural dust devils on Earth are observed on a variety of surface roughnesses and slopes. On Mars, many dust devils are observed traversing crater walls or hilly terrain, although most seem to form on flat surfaces. Surface roughness may play a significant role in determining how much dust is lofted into the atmosphere [1,2].

Methodology: Three sets of roughness elements were used in conjunction with the *Arizona State University Vortex Generator* (ASUVG), using small, medium, and large roughness beds. All of the roughness elements are cut from wooden dowel rods (0.64, 1.91,and 2.54 cm diameters), placed in regular arrays beneath the vortex generator. Dowel rods were used because of their circular cross-section, and because the vortex's incidence direction is not predictable, minimizing edge effects from the roughness elements. The small element bed has a height (H) of 0.64 cm and a spacing (D) of 4.76 cm resulting in a H/D of 0.1330. The medium elements are 1.59 cm high with a spacing of 3.18 cm resulting in a H/D of 0.4992. The large elements are 2.54 cm high with a spacing of 2.54 cm resulting in a H/D of 1.0000. The ratio H/D serves as a surrogate for the aerodynamic roughness height. A linear array of 21 pressure transducers placed with the ports through the test beds allow the pressure well at the surface to be measured for each roughness bed and then compared to previously published data for smooth surfaces [1]. From the pressure well data, assuming cyclostrophic balance, the maximum tangential velocities and core radii for each run can be calculated by curve-fitting to the Lamb-Oseen vortex model [1,2].

Results: In general, an increase in roughness decreases the tangential velocities and increases core radii. This result is attributed to conservation of angular momentum from expanding flow around the roughness elements (Figures 1 and 2), although there could be a scaling effect. In the ASUVG, driven vortices might not adapt to changing conditions on the surface in the same way natural systems due to complex interactions between the thermal and mechanical components of the vortex. From a mechanical view, non-erodable roughness elements should affect the flow by conservation of momentum as is observed here. Regardless, this result has implications for natural dust devils. Power in a dust devil is a combination of thermal energy radiated from the ground interacting with local winds, which allows the vortex to stabilize and persist. Dust devils traveling over varying surface roughness could lose energy as is observed due to angular momentum conservation or they might have other mechanisms for maintaining stability over such surfaces. Whether or not dust devils maintain stability over greatly varying surface roughnesses could greatly affect the amount of material that is lofted into the atmosphere.

Mars Application: On Mars, dust devils traversing rougher terrain would contribute less to the global atmospheric dust budget than those traveling over equally dusty smooth surfaces. Detailed measurements of rock abundances could lead to estimations of surface roughness allowing dust devil fluxes to be constrained in the future. Orbital track analyses might also be constrained by similar roughness analyses. Roughness differences in places like Amazonis Planitia (where there are high numbers of observed dust devils but few tracks) or Hellas Basin (where there are large numbers of tracks but few observed dust devils) could explain some of the observational differences in track densities.

References: [1] Greeley et al. (2003) *JGR, 108(E5),* 5041. [2] Neakrase et al. (2006), *GRL.* [3] Fisher et al. (2005) *JGR, 110, doi:10.1029/1003JE002165.* [4] Balme et al. (2003) *JGR, 108(E8) doi:10.1029/2003JE002096.*

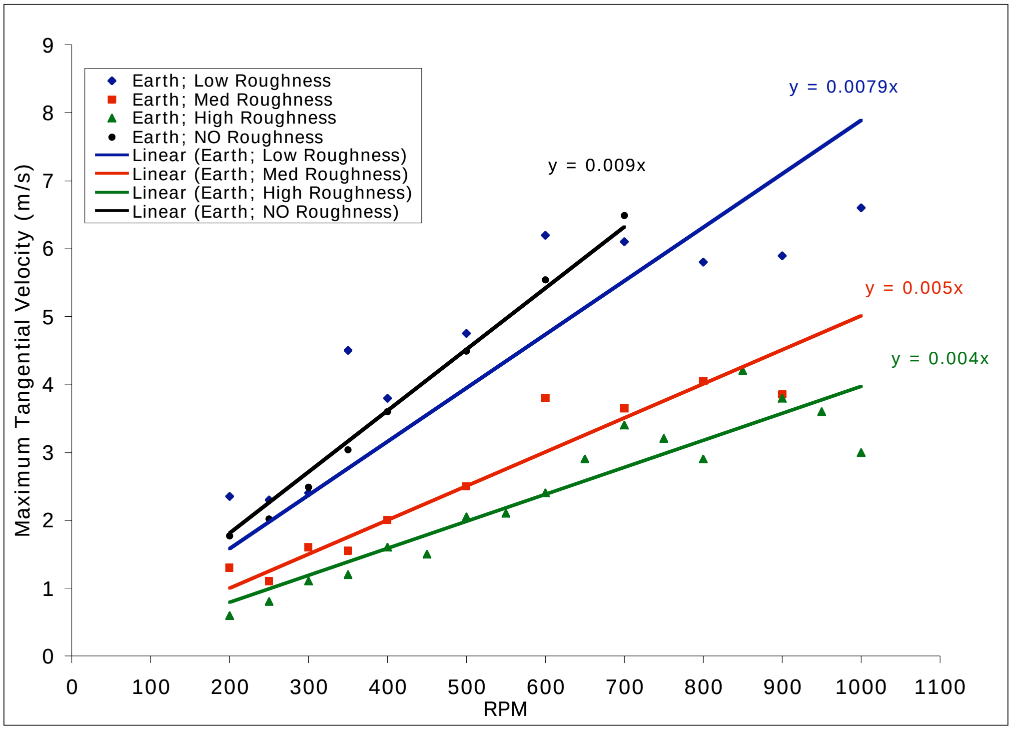

Figure 1. A plot of maximum tangential velocities as a function of ASUVG RPM. Best fit lines show trends for no roughness (black circles), low roughness (blue diamonds), medium roughness (red squares), and high roughness (green triangles).

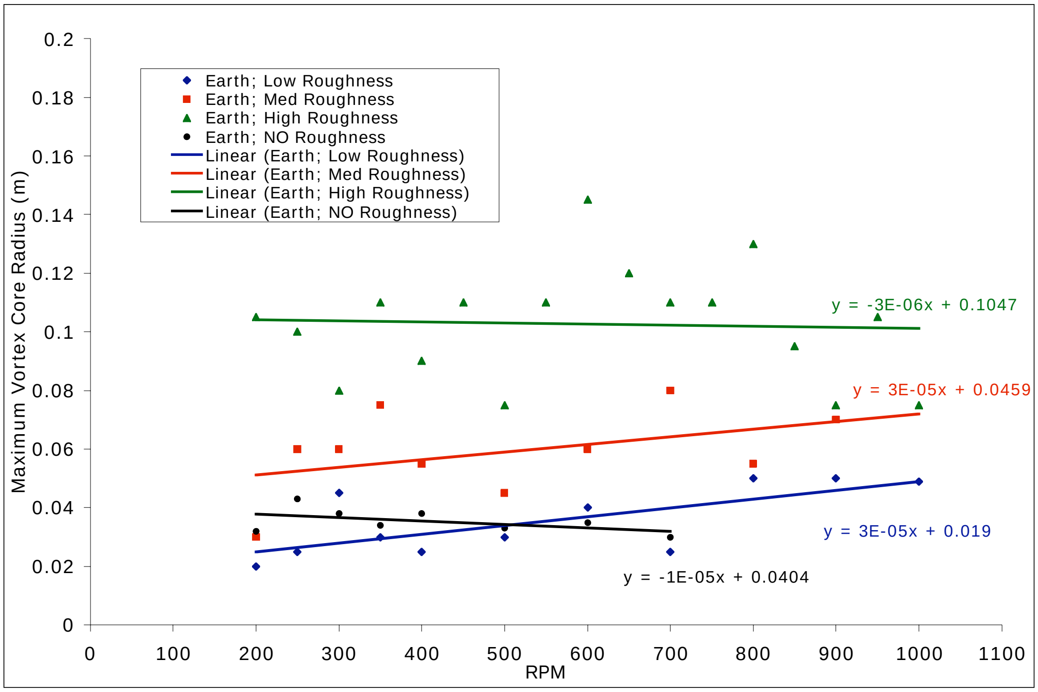

Figure 2. A plot of core radius as a function of ASUVG RPM, showing an increase with roughness. Best fit lines show trends for no roughness (black circles), low roughness (blue diamonds), medium roughness (red squares), and high roughness (green triangles).