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AEOLIAN PROCESSES ABOARD A SPACE STATION: SALTATION AND PARTICLE TRAJECTORY ANALYSIS

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The type of wind tunnel we propose to use to study aeolian processes aboard a space station consists of two concentric rotating drums. The space between the two drums comprises the wind tunnel test section. Differential rates of rotation of the two drums would provide a wind velocity with respect to either drum surface. Rotation of the outer drum provides a "pseudo" gravity ("pseudo" in the sense that a gravity force acts on the particle only when it is resting on the outer drum surface). This type of wind tunnel is hence referred to as a Carrousel Wind Tunnel (CWT). Preliminary results of measured velocity profiles made in a prototype (CWT) indicate that the wall bounded boundary-layer profiles are suitable to simulate flat plate turbulent boundary layer flow.

Once particles are airborne, the forces acting on individual grains in their trajectories are the particle weight and the aerodynamic lift and drag. The two-dimensional flat-plate Cartesian coordinate equations of motion of a particle moving through the air can be written as

$$\frac{4}{3}\frac{\rho_p}{\rho} D_p \ddot{x} = \dot{y} V_r C_L - (\dot{x} - u) V_r C_D \qquad (1)$$

$$\frac{4}{3}\frac{\rho_p}{\rho} D_p \ddot{y} = - (\dot{x} - u) V_r C_L - \dot{y} V_r C_D - \frac{4\rho_p g D_p}{3\rho} \qquad (2)$$

$$V_r^2 = (\dot{x} - u)^2 + \dot{y}^2 \qquad (3)$$

The last term in Equation 2 is the weight factor. Experimental and calculated trajectories for zero and one-gravity conditions have been calculated. With the elimination of the weight factor under zero-gravity, the only forces remaining are aerodynamic. Thus, experiments conducted in zero-gravity would enable direct assessment of aerodynamic lift and drag.

In order to assess the suitability of CWT in the analysis of the trajectories of windblown particles, a series of calculations was conducted comparing cases for gravity with those of zero gravity. The equations of motion for an airborne particle, assuming no lift force, are (in a polar coordinate system, Greeley and Iversen, 1983),

$$\ddot{r} - r\,\dot{\theta}^2 - g\cos\theta + \left(\frac{3\rho C_D \dot{r}}{4\rho_p D_p}\right) V_r = 0 \tag{4}$$

$$r\,\ddot{\theta} + 2\,\dot{r}\,\dot{\theta} + g\sin\theta - \left(\frac{3\rho C_D}{4\rho_p D_p}\right) [U(r) - r\,\dot{\theta}]\, V_r = 0 \tag{5}$$

$$V_r = \{\dot{r}^2 + [U(r) - r\,\dot{\theta}]^2\}^{1/2} \tag{6}$$

Equations 4, 5, and 6 were solved for several example cases. The drag coefficient, C_D, is a function of Reynolds number, assuming a spherical particle (White et al., 1975). Figure 1 illustrates particle trajectories in CWT for zero-gravity atmospheric-pressure conditions. The coordinate system is fixed to the particle launch point and rotates with the outer cylinder. In inertial space the trajectories are straight lines, but relative to an observer standing on the launch point of the rotating outer drum, as plotted, the trajectories are curved. The initial inward radial velocity of the particle is assumed to be equal to the surface friction speed of the outer cylinder. The assumed wind speed profile for the calculation was taken from prototype velocity profile measurements. Since the only force acting on the particle in CWT is aerodynamic, significant differences between trajectories with and without gravity should enable much more accurate determination of the aerodynamic forces (drag and lift) than is possible in an Earth-based facility. We conclude that the CWT can yield significant data on the trajectories of windblown particles impossible to acquire under the effect of gravity.

Analyisis of particle trajectories in a zero-gravity environment would enable the determination of the aerodynamic forces on windblown particles by using high-speed motion picture obtained during the experiments. The lift and drag forces would be determined by measuring particle accelerations, particle speeds, and wind speeds, and applying Equations 4, 5, and 6 to the results.

In conclusion, results from our calculations demonstrate that a wind tunnel of the carrousel design could be fabricated to operate in a space station environment and that experiments could be conducted which would yield significant results contributing to the understanding of the physics of particle dynamics.

References

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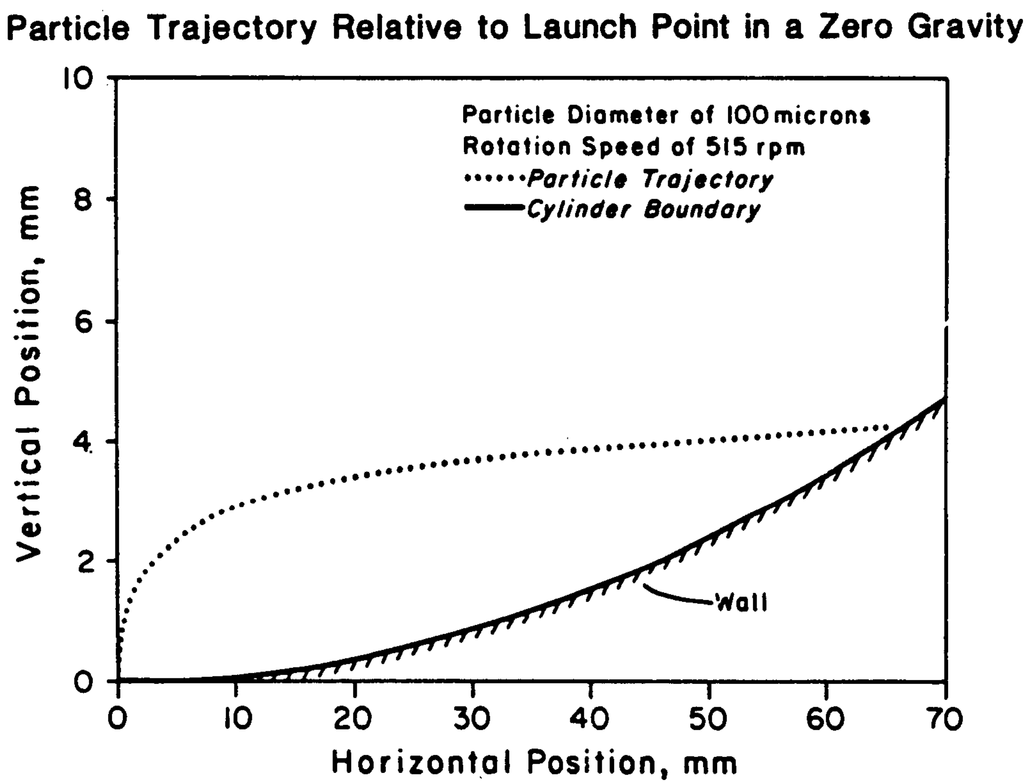

Figure 1 Calculated particle trajectory in zero-gravity, with one atmosphere of air, based on assumed drag characteristics. The outer cylinder is not rotating and the coordinate system is fixed to it at the launch point. The initial inward radial velocity of the 100 μm diameter particle is assumed to be 32.6 cm/s, the friction speed of the flow near the outer cylinder.