SEDIMENT-TRANSPORT EXPERIMENTS IN ZERO-GRAVITY

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One of the important parameters in the analysis of sediment entrainment and transport is gravitational attraction. The availability of a laboratory in Earth orbit would afford an opportunity to conduct experiments in zero-gravity and variable-gravity environments. Elimination of gravitational attraction as a factor in such experiments would enable other critical parameters (such as particle cohesion and aerodynamic forces) to be evaluated much more accurately. A Carousel Wind Tunnel (CWT) is proposed for use in conducting experiments concerning sediment particle entrainment and transport in a space station. The type of wind tunnel we propose 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 provides 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).

In order to test the concept of this wind tunnel design, a 1/3 scale model Carrousel Wind Tunnel (CWT) was constructed and calibrated. In this prototype, only the inner drum rotates, whereas in the final configuration, both drums would rotate at controllable, variable speeds. The outer drum is sealed along its periphery, but there is a small gap between the sides of the inner drum and the outer drum.

Threshold Experiments

Threshold (u_{*_t}) defines the minimum winds required to initiate particle motion and is the fundamental factor in aeolian processes. In the determination of a general expression of the threshold wind speeds for small (~sub-millimeter) particles, the effect of aerodynamic forces tending to dislodge a particle from a bed of loose granular material is equated to the effect of opposing forces, namely the particle weight (W) and interparticle cohesion (I). The relative magnitudes of these forces have been deduced only approximately from wind tunnel tests of threshold speed (Iversen et al., 1976; Greeley et al. 1980a, Iversen and White, 1982).

The elimination of particle weight in the threshold force equation--as could be accomplished by conducting experiments in a weightless environment--would enable a more accurate assessment of the other factors. The equation of equilibrium for a small particle at threshold is

$$Da + Lb + M = Ic + Wb \qquad (1)$$

Where D, L, and M are aerodynamic drag, lift, and moment, respectively, W is particle weight, I is cohesive force, and a, b, and c are distances from lines of action of the forces to the overturning point. Elimination of the weight term would aid in the determination of the form and magnitude of the cohesive force term at the moment of threshold.

All of the previous experiments have been conducted under conditions of Earth's gravity. It would be extremely valuable to extend the matrix of experiments to include values of artificial gravity above and below that experienced on Earth. This could be accomplished in CWT by placing a bed of particles on the inner surface of the outer drum and rotating the outer drum at different rotational speeds. The rotating outer drum provides an acceleration directed radially outwards, normal to the surface, thus creating artificial gravity. While rotating the outer drum at a constant rate to maintain a constant value of artificial gravity, the inner drum speed can be changed to increase the value of outer-drum wind-friction speed until the top layer of particles leaves the surface at which point the threshold wind friction speed can be ascertained.

Zero-gravity threshold experiments are valuable because of the elimination of the weight term in Equation (1). These experiments would be conducted by rotating only the inner drum, accelerating its speed until threshold is reached.

CWT Flow Characteristics

A series of experiments was conducted in a prototype carousel wind tunnel (CWT) to determine the flow properties. Taylor in 1935 hypothesized nearly potential flow between concentric rotating cylinders with the exception of boundary layers (governed by Prandl's mixing - length theory) near the outer and inner drum walls. Wind velocity profiles were obtained using a TSI Model 1010 hot-wire anemometer. The data show conformity to Taylor's hypothesis and good lateral uniformity of flow. Discrepancies between theory and experiment are due primarily to secondary flows in the wind tunnel cross section which seem to be concentrated near the inner drum. The flow is close to the desired two-dimensionality. Turbulence levels of 6% to 10% were measured within the inner and outer boundary layers. In CWT it is important that the mixing-length theory govern the boundary-layer flow adjacent to the curved cylinder wall surfaces because the same theory governs the flow adjacent to a plane surface and would be comparable to natural conditions and to conditions used in previous threshold experiments (Greeley et al., 1976, 1980b; Iversen et al., 1976). Experiments were performed in CWT to ascertain if these assumptions are correct and if Taylor's hypothesis is valid. For cases in which only the inner cylinder rotates (as in the prototype CWT) and assuming that the surfaces of the cylinder walls are aerodynamically smooth, the following equations for the flow between two infinitely long cylinders can be derived:

inner layer (Prandtl boundary layer)

$$U = R_i\omega - u_{*_i}\{2.5 \ln[(r - R_i)u_{*_i}/\nu] + 5.5\}$$

$$\text{for } R_i/R_o + (\nu/u_{*_i}R_o)e^{0.4R_i\omega/u_{*_i}} \leq r/R_o \leq r_2/R_o \tag{2}$$

central layer (potential inviscid layer)

$$U = KR_i\omega R_o/r \quad \text{for } r_2/R_o \leq r/R_o \leq r_1/R_o \tag{3}$$

outer layer (Prandtl boundary layer)

$$U = u_{*_o} \{5.5 + 2.5 \ln [(1 - \frac{r}{R_o}) R_o u_{*_o} /\nu]\}$$

$$\text{for } r_1/R_o \leq r/R_o \leq 1 - 0.1108/(R_o u_{*_o} /\nu) \qquad (4)$$

Preliminary results show uniform flow and boundary layer properties that are in agreement with theory. Experiments were conducted in the prototype to determine the feasibility of studying various aeolian processes and the results were compared with various numerical analyses. Several types of experiments appear to be feasible utilizing the proposed apparatus.

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