REYNOLDS NUMBER EFFECTS ON SURFACE SHEAR STRESS PATTERNS AROUND ISOLATED HEMISPHERES

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Obstacles projecting into the wind stream alter the shear stress on the surface around them, thus altering the erosion, transportation, and deposition of aeolian sediment. This study is concerned with the effect of Reynolds number on the pattern of shear stress on the surface around an isolated hemisphere. An understanding of Reynolds number effects is necessary if wind tunnel results are to be scaled up to natural situations for meaningful applications.

Surface shear stress was measured using the naphthalene sublimation technique outlined by Lee and Greeley (this volume). The hemisphere used is 0.033 m high and was immersed in the lower portion of the 0.13 m boundary layer. Surface shear stress, τ_o, is often presented as the friction velocity, u_*, where $u_* = (\rho_a \tau_o)^{0.5}$ with ρ_a the atmospheric density.

For this study Reynolds number, Re, is defined as

$$\text{(1)} \quad Re = (u_* \; h) / \upsilon$$

where h is the hemisphere height and υ is the kinematic viscosity (1.164×10^{-5} m^2 sec^{-1} for the 35 ^oC air used in the experiments (from Oke, 1978)).

Figure 1 displays the surface shear stress patterns for Re of 1360 to 2977. At the threshold of motion for fine sand this corresponds to object heights of 0.10 to 0.22 m on Earth, 0.76 to 1.67 m on Mars, and 0.024 to 0.053 m on Venus (all values calculated from information in Fig. 3.17 of Greeley and Iversen, 1985).

Over the entire range of Re there is an increase in relative shear stress at all locations except for a small zone immediately downwind of the hemisphere. The highest relative shear stress is immediately in front of the object, presumably caused by reversing flow in the lowest layers of the boundary layer due to fluid impact on the object. (see Baker, 1979, for a more detailed discussion of this phenomenon). The region of low relative shear stress is due to sheltering by the object. Relative shear stress is high behind this region due to increased turbulence, as found by Greeley et al. (1974) for raised rim craters and Greeley (1986) for domical hills.

The most obvious change in the pattern as Reynolds number increases is in the strength of the horseshoe vortex. Figure 1A shows a strong vortex downwind of the edge of the hemisphere. As Re increases, however, the horseshoe vortex decreases in strength. This is likely to be due to an increase in flow separation with Re resulting in the flow tending to wrap around the object at lower wind speeds and flow over it at higher speeds. In Figure 1D a reattachment zone appears from x = 2h to x = 3.5h along the centerline.

In a discussion of air flow around objects Snyder (1972) cites evidence suggesting that for a given object shape there is a minimum Reynolds number above which the flow characteristics are essentially Reynolds number independent. The value of this Reynolds number appears to increase as shapes become more streamlined. Figure 1 shows that for hemispheres this minimum Reynolds number has not been achieved at the wind speeds used. (For Reynolds number defined by freestream wind speed, u_∞, this corresponds to a range of $(u_\infty h)/\upsilon$ =29515 to 58888.)

This experiment shows that the surface shear stress pattern is strongly affected by Reynolds number, at least within the range of Re used. The strength of the horseshoe vortex decreases with increasing Re. This is presumably due to a decrease in flow around the sides of the hemisphere and an increase in flow over the object as Reynolds number increases.

References

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Figure 1. Map views of surface shear stress patterns around a hemisphere. Flow is from negative x/h to positive x/h. Symmetry can be assumed for the patterns. Isolines show relative friction velocity: measured u_* divided by u_* on undisturbed portion of naphthalene surface. Location relative to the hemisphere center is made dimensionless by dividing x and y by object height. '?' indicates area where pattern is not clear with the measurement grid used.