

ABSTRACT

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This thesis investigates the forces, flow patterns, and significant transitions occurring in granular flows around completely immersed objects and is divided into three parts. In the first part, flow around an immersed cylinder is investigated for accelerating dilute granular flows using hard-particle discrete element method (DEM) computer simulations. Simulation measurements of the drag force, F_d , are expressed in terms of a dimensionless drag coefficient, $C_d = F_d / [\frac{1}{2} \rho \nu U^2 (D + d)]$, where ρ is the particle density, ν is the upstream solid fraction, U is the upstream instantaneous velocity, and D and d are the cylinder and particle diameters, respectively. Measurements indicate that the cylinder's unsteady drag coefficient does not vary significantly from its steady (non-accelerating) drag coefficient for both frictionless and frictional particles. These results indicate that the added mass for the flow is negligible. However, the drag coefficient is larger than its nominal value during an initial transient stage during which a bow shock wave develops in front of the cylinder. Once the shock has developed, the drag coefficient remains constant despite the stream's acceleration. The duration of the shock development transient stage is a function of the number of particle/cylinder collisions.

In the second part of this thesis, the range of solid fractions over which the dilute flow drag force scaling is applicable is examined. For a given jet width, there exists a critical solid fraction above which the dilute drag scaling law fails to hold due to jamming of the flow. For inelastic, non-cohesive, frictionless, circular particles (in 2-D), the deviation from this scaling law for an infinite jet width is encountered when the solid fraction approaches a value such that there is constant particle-particle contact.

This solid fraction corresponds to the packing of circular particles in a square lattice with a solid fraction of 0.785.

Lastly, drag correlations for 3-D, dilute granular flow around an immersed sphere and cylinder are established. The drag coefficient based on the effective projected area of the obstacle is found to be a function of the flow Knudsen number, $\text{Kn} = d/[6\nu D]$, as well as a function of the normal coefficient of restitution, ϵ_N , and friction coefficient, μ . Correlations for the drag coefficient in terms of the Knudsen number are presented for Knudsen numbers greater than 0.08 for the sphere and 0.03 for the cylinder.