

MAR07-2006-000724

Abstract for an Invited Paper  
for the MAR07 Meeting of  
the American Physical Society

### **Rapid Granular Flows: From Kinetic Theory to Hydrodynamics**

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Rapid granular flows are defined as flows in which the time scales for the particle interactions are small compared to the inverse of the strain rate, so that the particle interactions can be treated as instantaneous collisions. We first show, using Discrete Element simulations, that even very dense flows of sand or glass beads with volume fraction between 0.5 and 0.6 are rapid granular flows. Since collisions are instantaneous, a kinetic theory approach for the constitutive relations is most appropriate, and we present kinetic theory results for different microscopic models for particle interaction. The significant difference between granular flows and normal fluids is that energy is not conserved in a granular flow. The differences in the hydrodynamic modes caused by the non-conserved nature of energy are discussed. Going beyond the Boltzmann equation, the effect of correlations is studied using the ring kinetic approximation, and it is shown that the divergences in the viscometric coefficients, which are present for elastic fluids, are not present for granular flows because energy is not conserved. The hydrodynamic model is applied to the flow down an inclined plane. Since energy is not a conserved variable, the hydrodynamic fields in the bulk of a granular flow are obtained from the mass and momentum conservation equations alone. Energy becomes a relevant variable only in thin 'boundary layers' at the boundaries of the flow where there is a balance between the rates of conduction and dissipation. We show that such a hydrodynamic model can predict the salient features of a chute flow, including the flow initiation when the angle of inclination is increased above the 'friction angle', the striking lack of observable variation of the volume fraction with height, the observation of a steady flow only for certain restitution coefficients, and the density variations in the boundary layers.