Drag-Force in Supersonic Dense Gas-Solid Flow

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Multiphase CFD at macrocales has been applied to simulate non-ideal explosion dynamics. One of the major deficiencies in this approach relates to the specification of momentum and heat exchanges between particles and the supersonic turbulent gas phase in a dense gas-solid flow that appears in the near field of explosion. To date, most drag and heat transfer correlations have been developed for a single sphere or for dilute particles in a fairly uniform flow, and the effects of solid compressibility, shock/wake interactions, jetting (due to the presence of neighbouring particles) and particle collisions have not been considered. As a result, instabilities of particle trajectory cannot be described and mean particle velocities are generally under-predicted (Zhang et al., 2001). Due to a lack of resolution in space and time, it is difficult for experiments to gain insight into the influences of these factors on particle dynamics. Alternatively, this can be achieved by conducting mesoscale modeling with a length scale of 1μm - 1 cm and a time scale of 1 ns - 1 μs. For example, Ripley et al. (2006) quantified momentum and heat transfer from a condensed explosive (nitromethane) to the metal (aluminum) particle during shock and detonation conditions by defining "transmission factors", which were measured immediately after the shock interaction time (d_p/D; d_p is particle diameter and D is shock velocity). The effects of different d_p/L (L is the detonation reaction zone thickness) and volume fraction on the transmission factors were examined. Further studies are necessary to extend mesoscale modeling into the subsequent region of dense gas-solid flow, to explore dominant transfer mechanisms among interactions of particle-attached flows (bow-shocked and wake flows), jettings and collisions, and their influences on the overall force or drag acting on the particles with respect to the particle mean motion and trajectory perturbation that leads to cluster or agglomeration of particles in a jetting form (see Figure 1).

In this study, we will apply mesoscale modeling to gain an understanding of particle-attached flow interactions in a dense gas-solid flow and their influence on particle motions in the main flow direction and the perturbation/instabilities of the particle trajectories in the transverse direction. A distributed drag-force model (see, e.g., Lien et al., 2005) in the post shock-interaction region is then proposed based on the concept of ensemble averaging as outlined below by reference to Figure 2:

1. For each realization, a fixed number of cylindrical particles are randomly distributed in the computational domain. Perform 2-D large eddy simulation from scratch until quasi-steady state is reached before releasing particles travelling at a speed of u_p.
2. Compute C_D (effective drag coefficient) in the main flow and transverse perturbation directions and ϕ (volume fraction) in the averaging volume indicated in Figure 2 as a function of time until all particles leave the computational domain.
3. Time average C_D and ϕ for each realization, and repeat (1) and (2) for several realizations in order to determine ensemble averages for C_D and ϕ at a given Reynolds number.
4. Repeat (1) to (3) for various flow conditions and solid volume fractions to generate a functional form for C_D.

Figure 1. Formation of particle clusters in a jetting form during cylindrical dispersal of aluminum particles in air.

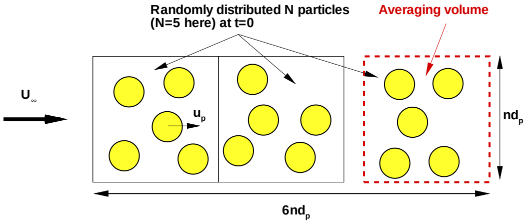

Figure 2. Averaging volume for gas and particle phases for one realization.

References

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