

Modeling particle-laden turbulent gas flows

Donald Koch
Cornell University

An important challenge for many energy-related applications is to develop accurate models for the turbulent flow of gases laden containing a small volume fraction but order one mass loading of particles. Such flows differ significantly from single phase turbulent flows. The particles typically are inhomogeneously distributed, a feature that enhances their influence on the gas flow and alters the rate of heat and mass transport. Engineering methods for predicting single-phase flows, including large eddy simulations (LES) and Reynolds averaged Navier-Stokes (RANS) equations exploit the considerable understanding that has been developed for single-phase turbulence. Similar predictions for particle-laden turbulent flows would require a better understanding of the instabilities that lead to fluctuations in the particle concentration and in the particle and fluid velocities in these flows. It is particularly important to be able to model the small scale fluctuations, since LES and RANS solves for the large scale motion, while modeling the effects of the small scales.

We have recently identified an instability mechanism for sheared particle-laden gas flows. This mechanism involves the preferential concentration of particles in low vorticity regions of the flow and the gravity-driven motion produced by this preferential concentration. For example, a uniform linear shear flow (the base state for the stability analysis) has a uniform vorticity and therefore in itself produces no preferential concentration. However, if we consider a small perturbation to this flow, the perturbation will increase and decrease the vorticity in different regions of the flow, thereby creating particle concentration variations. These particle concentration variations create a buoyancy driven flow that reinforces the original velocity disturbance, leading to a growth of the fluctuations. I am interested in developing a model for how turbulence is modulated by this mechanism by modeling the larger scales of turbulence as a locally linear flow field which exchanges energy and particle concentration variations with the small scale disturbance. The validity of the modeling approach could be validated by comparison with direct-numerical simulations of turbulent gas-solid flows with two-way coupling. The validated model could then act as the subgrid model for a large eddy simulation or as a closure approximation for a set of averaged equations which could be applied to large-scale flows occurring in energy engineering applications.

Having established the efficacy of such an approach to modeling turbulent flows in the context of flows dominated by shear and gravity, it would be interesting to consider other instability mechanisms. A conceptually simple extension would be to consider the coupled effects of shear and an acceleration of the particle-laden gas. If the rate of acceleration were independent of time, this problem would be identical to the shear/gravity case discussed above. However, in practice, the acceleration, which could arise from the mean motion of the gas as would be the case if the flow is expanding or contracting or from the turbulent fluctuations themselves, would evolve with time in either a deterministic or stochastic manner.

I would be interested in performing the stability analysis and doing the initial model development and validating the model using DNS in collaboration with Lance Collins at Cornell. I would be interested in working with an external collaborator who would like to develop and implement an LES or averaged equation based simulation.

