Mechanical Engineering Doctoral Defense

Modeling Particle-Laden Turbulent Flows Using the Conditional Quadrature Method of Moments

School for Engineering of Matter, Transport and Energy

Dennis Dunn

Advisor: Dr. Kyle Squires

abstract

Conventional fluid dynamics models such as the Navier-Stokes equations are derived for prediction of fluid motion at or near equilibrium, classic examples being the motion of fluids for which inter-molecular collisions are dominant. Flows at equilibrium permit simplifications such as the introduction of viscosity and also lead to solutions that are single-valued. However, many other regimes of interest include “fluids” far from equilibrium; for example, rarefied gases or particle-laden flows in which the dispersed phase can be comprised of granular solids, droplets, or bubbles. Particle motion in these flows is typically not dominated by collisions and may exhibit significant memory effects; therefore, is often poorly described using continuum, field-based (Eulerian) approaches. Additionally, non-equilibrium flows generally lack a straightforward counterpart to viscosity and their multi-valued solutions cannot be represented by most Eulerian methods. This strongly motivates different strategies to address current shortcomings and the novel approach adopted in this work is based on the Conditional Quadrature Method of Moments (CQMOM). In CQMOM, moment equations are derived from the Boltzmann equation using a quadrature approximation of the velocity probability density function (PDF). CQMOM circumvents the drawbacks of current methods and leads to multivariate and multidimensional solutions in an Eulerian frame of reference. In the present work, the discretized PDF is resolved using an adaptive two-point quadrature in three-dimensional velocity space. The method is applied to computation of a series of non-equilibrium flows, ranging from simple two-dimensional test cases to fully-turbulent three-dimensional wall-bounded particle-laden flows. The primary contribution of the present effort is on development, application, and assessment of CQMOM for predicting the key features of dilute particle-laden flows. Statistical descriptors such as mean concentration and mean velocity are in good agreement with previous results, for both collision-less and collisional flows at varying particle Stokes numbers. Turbulent statistics and measures of local accumulation agree less favorably with prior results and identify areas for improvement in the modeling strategy.

April 09, 2015; 4:30 PM; ERC 593