“New subgrid models for inertial particle clustering in large-eddy simulations of turbulence”

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Abstract

An initially uniform distribution of inertial particles will spontaneously organize themselves into clusters in a turbulent flow, driven primarily by the small-scale turbulent fluctuations. Accurate prediction of such clustering of inertial particles, along with their relative velocity statistics, is essential for computing their binary collision rates, an important quantity that determines the evolution of their size distribution. In large-eddy simulations (LES) of turbulent flows, only the large-scale turbulent fluctuations are represented on the grid whereas the small-scales (or subgrid scales) need to be modeled. None of the existing LES subgrid models are able to capture the clustering and the relative velocity statistics of inertial particles. In this work, we present new subgrid models designed to recover these statistics in a LES. We first consider the effect of LES filtering on our statistics of interest, and lay down the requirements of a LES subgrid model designed to recover them. We then consider a subgrid model based on kinematic simulations of turbulence, which we call KSSGM, and show that it gives excellent results for high-inertia particles (St > 2.0). Here, particle inertia is parameterized by the Stokes number (St) defined as the ratio of the particle response time to the Kolmogorov time-scale. We investigate the reasons for the failure of the KSSGM at low St, and identify some of the detailed small-scale statistics that a subgrid model needs to recover in order to capture clustering correctly. We conclude that none of the existing subgrid models are capable of recovering the necessary small-scale statistics, and recognize the difficulty in doing so in a single-particle framework.

We then decide to focus our attention on a two-particle framework, based on the understanding that clustering is driven by two-point dynamics, and the recognition that all of the existing theories of particle clustering and collisions are formulated in this framework. We then develop a novel satellite particle simulation (SPS) methodology that allow us to efficiently simulate pair-wise interaction of particles in turbulence, thereby providing an ideal test-bed for the development and testing of two-particle models. We derive models from existing theories of inertial particle clustering primarily focussing on low St, and test them using the SPS. We focus on a class of models, which we call drift-diffusion models (DDM), and show how they can be derived from statistical mechanical theories of clustering. We consider the theories by Chun et al. 2005 (CT) and Zaichik & Alipchenkov 2009 (ZT). We show that DDM-CT works well for St < 0.3, whereas DDM-ZT works well for St < 0.2. Such models represent an entirely new framework for subgrid modeling of inertial particle motion in a LES, and the initial results provide strong evidence regarding the viability of such an approach.

The public is encouraged to attend this seminar, which constitutes the open portion of the candidate’s dissertation defense (i.e., B exam). The closed portion of the exam will follow the open seminar.

Biographical sketch

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