Mechanical Engineering Dissertation Defense

A novel Volume Filtered Immersed Boundary (VF-IB) method towards high fidelity multiphase simulations.

School for Engineering of Matter, Transport and Energy

Himanshu Dave

Advisor: Prof. Mohamed Houssem Kasbaoui

Abstract

This dissertation presents a novel Volume-Filtered Immersed Boundary (VF-IB) method to achieve high fidelity particle-laden simulations. First, we study particle-laden flows using the well-established Euler-Lagrange method with four-way coupling to investigate how varying the parameters of the particles affect the flow characteristics. Later we show a novel Volume-Filtered Immersed Boundary formulation that is physically and mathematically rigorous, and does not rely on any numerical considerations. Additionally, we extend the concept of volume-filtering to hyperbolic partial differential equations and explore the effect of the sub-filter scale term produced as an artifact of the volume-filtering approach.

We investigate the mechanisms by which inertial particles dispersed at semi-dilute conditions cause significant drag-reduction in a turbulent channel flow at $\Rey_\tau = 180$. We consider a series of four-way coupled Euler-Lagrange simulations where particles having friction Stokes number $\Sto^+ = 6$ or 30 are introduced at progressively increasing mass loading from $M=0.2$ to 1.0. The simulations show that $\Sto^+ = 30$ particles cause large drag-reduction, whereas $\Sto^+ = 6$ particles cause large drag increase. We find a distinctive feature of drag-reducing particles which consists in the formation of extremely long clusters, called ropes. These structures align preferentially with the low-speed streaks and contribute to their stabilization and suppression of bursting.

Due to the large regime map for particle-laden flows because of the many parameters that dictate the solution, higher fidelity methods are needed. We present a novel framework to deal with static and moving immersed boundaries (IB) based on volume-filtering. In this strategy, called Volume-Filtering Immersed Boundary (VFIB) method. This method produces a more accurate approach to model the interface without any numerical fixes. The process of volume-filtering converts the boundary conditions into bodyforces that act on the right-hand side of the transport equation and allows for accurate volume fraction computation. Finally, we extend the concept of volume filtering to hyperbolic partial differential equations and show second order convergence. We also explore the effect of τ_sfs and show that it scales with $1/\delta_f^2$. modeling the term can help achieve better accuracy at coarse resolutions.

April 4, 2024; 1:00 PM; ERC 490

Arizona State University