Aerospace Engineering Dissertation Defense

Mechanisms of Sediment Transport and Flow Modulation in Numerical Simulations

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Abstract

Solid particle suspensions are commonly encountered in environmental and industrial problems, but the ways sediment interacts with and modifies turbulence are poorly understood. This dissertation investigates sediment-turbulence interaction in three complimentary regimes, using state of the art numerical methods, isolating distinct mechanisms of modulation in each regime.

In Euler-Lagrange simulations of an oscillatory boundary layer over a cohesionless particle bed reveal significant alteration to the fluid velocity profile due to bed interface permeability. The no-slip condition does not apply at the bed fluid interface, allowing a significant slip velocity to develop and a corresponding reduction in the shear stress at the bed surface. Additionally, as some particles are set in motion and a clear bedform emerges, displaying rolling grain ripples, or a suspended sediment layer depending on the Reynolds number. In the former case, the ripples generate increased flow disturbances, departing from the laminar flow at lower Reynolds numbers. In the latter case, the entrained particles in the suspension layer generate additional fluctuations through the large feedback force on the fluid.

Next, I consider high suspended particle concentrations in Euler-Lagrange simulations of turbulent channel flow. The particles are treated as point particles, having diameters smaller than the smallest turbulent scales, such that I can ignore finite-size effects. Increasing particle volume fraction systematically reduced streamwise velocity and velocity fluctuations. At lower concentrations, the flow modification is captured almost entirely by increased apparent viscosity. However, as sediment concentration increased, particle stress becomes dominant, causing a reduction in mean and fluctuating velocities which cannot be accounted for by apparent viscosity alone.

Finally, I investigated the influence of finite-size particles, using the Volume-Filtered Immerse Boundary Method, in a turbulent channel and high sediment volume fraction. Preliminary results show that finite-size particles lead to decreased streamwise velocity, but increased velocity fluctuations.

Together, these studies provide insight on sediment interactions with turbulent regimes by isolating the mechanisms of interactions in three distinct regimes.

October 20, 2025; 1:00pm; SS 304

Arizona State University