Proceedings of the Canadian Society for Mechanical Engineering International Congress
32nd Annual Conference of the Computational Fluid Dynamics Society of Canada
Canadian Society of Rheology Symposium
CSME-CFDSC-CSR 2025
May 25–28, 2025, Montréal, Québec, Canada

Simulation and modeling of non-canonical wall-bounded turbulent flows

Junlin Yuan
Mechanical Engineering Department, Michigan State University, East Lansing, United States of America
*junlin@msu.edu

ABSTRACT

Turbulence research has historically concentrated on canonical flows over smooth flat plates with uniform freestream conditions. However, engineering and environmental applications—including flows around hydraulic turbine blades, naval platforms, and riverine systems—involve dynamically complex flows influenced by surface roughness, curvature, permeability, and unsteadiness. Consequently, conventional turbulence models demonstrate limited utility in practical design and analysis. This research aims to incorporate essential physics into predictive models to enable consistent characterization of turbulence across diverse flow complexities.

This presentation first addresses understanding and modeling for rough-walled, equilibrium and non-equilibrium turbulent boundary layers. Through direct and large-eddy simulations (DNS and LES), we demonstrate how wall roughness fundamentally alters turbulence structure under strong spatial and temporal gradients. Data and insights are used to inform improved roughness-unresolved turbulence closures, including linear eddy-viscosity models, which have traditionally struggled to accurately predict flows with arbitrary roughness characteristics and freestream conditions.

The second segment explores DNS investigations of critical transport processes in riverine systems—natural turbulent flows bounded by rough, permeable substrates. A knowledge gap exists on how sediment grain-scale dynamics influence multiscale hydrologic processes. We conducted pore-resolved simulations of idealized configurations and show that sediment roughness—frequently neglected in existing predictive frameworks—serves as an important driver of transport in nature. Pore-scale dynamics can significantly influence those at large scales.