THERMAL & FLUIDS
ANALYSIS WORKSHOP
Ames Research Center 2025

NASA Ames Research Center
Moffett Field, CA
August 4–7, 2025

TFAWS2025-AERO-I-01

General-Purpose Machine-Learning Closure Model for Wall-Modeled LES

Adrian Lozano Duran
Caltech/MIT

Abstract

The predictive capabilities of computational fluid dynamics, which are critical for aerodynamic design, depend on the development of accurate closure models. However, no practical model has emerged as universally applicable across the wide range of flow regimes relevant to the industry. We introduce a closure model for large-eddy simulation, referred to as the Building-block Flow Model (BFM). This model is founded on the premise that a finite set of simple flows encapsulates the essential physics required to predict more complex scenarios. The BFM is implemented using artificial neural networks and introduces five unique advancements within the large-eddy simulation framework: (1) It is designed to predict multiple flow regimes, including laminar flow, wall turbulence under zero, favorable, and adverse mean-pressure gradients, separation, wall heat transfer, and wall roughness effects; (2) It leverages information-theoretic dimensional analysis to select the most relevant non-dimensional input/output variables; (3) It ensures consistency with numerical schemes and gridding strategies by accounting for numerical errors; (4) It is directly applicable to arbitrary complex geometries; and (5) It is scalable for future extensions to model additional flow physics (e.g., laminar-to-turbulent transition). The BFM is utilized to predict key quantities of interest across a wide range of cases, such as turbulent pipes, turbine blades with roughness, speed bumps, aircraft in landing configurations, and hypersonic flows in entry, descent, and landing vehicles.