Data-Driven Turbulence Modeling and Simulation: From RANS to LES

Turbulent fluid flows are characterized by a wide spectrum of spatial and temporal scales. Unfortunately, the cost of resolving these scales with Direct Numerical Simulation (DNS) grows quickly with Reynolds number, so we will be unable to apply DNS to industrial flows of interest for many years to come. Alternatively, one can model all scales using Reynolds Averaged Navier-Stokes (RANS) or just the smallest scales using Large Eddy Simulation (LES). RANS remains the turbulence modeling and simulation paradigm of choice in industrial computational fluid dynamics while LES continues to grow in popularity. However, state-of-the-art RANS and LES approaches are inaccurate for many industrial flows of interest, especially those exhibiting shallow to massive flow separation or transition to turbulence.

In this talk, I will present a new data-driven methodology which greatly improves upon the accuracy of state-of-the-art RANS and LES approaches. The proposed methodology relies on learning the components of the Reynolds stress tensor (in the context of RANS) or the components of the subgrid stress tensor (in the context of LES) in a particular flow-dependent reference frame — the strain-rate eigenframe. These components are typically smooth, thus state-of-the-art machine learning strategies are well suited for learning them. These components are also invariant under a change of coordinates, so the proposed methodology automatically yields Reynolds stress and subgrid stress models that are Galilean and frame invariant provided the model inputs are themselves Galilean and frame invariant. Lastly, the proposed methodology yields models whose stability characteristics are easily established, and in particular, it enables the construction of energy-stable Reynolds stress and subgrid stress models. I will present numerical results illustrating the proposed methodology's effectiveness in constructing data-driven Reynolds stress models for turbulent flows exhibiting shallow to massive flow separation, and I will conclude by demonstrating the methodology's capability to generate accurate data-driven subgrid stress models for turbulent and transitional flows.