Title : Regularized Reduced Order Models (Reg-ROMs) for Turbulent Flows

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Abstract : Over the past decade, several stabilization strategies have been developed to tackle the reduced order model (ROM) inaccuracy in the convection-dominated, under-resolved regime, i.e., when the number of degrees of freedom is too small to capture the complex underlying dynamics. In this talk, I will survey our group's work on regularized reduced order models (Reg-ROMs), which are simple, modular stabilizations that employ ROM spatial filtering of various terms in the Navier-Stokes equations (NSE) to alleviate the spurious numerical oscillations generally produced by standard ROMs in the convection-dominated, under-resolved regime. I will focus on three different types of Reg-ROM strategies: (i) the evolve-filter-relax ROM (EFR-ROM), which first filters an intermediate velocity approximation, and then relaxes it; (ii) the Leray-ROM (L-ROM), which filters the convective term in the NSE; and (iii) the time-relaxation ROM (TR-ROM), which filters the marginally resolved scales. Throughout my talk, I will highlight the impact made by ROM spatial filtering on the Reg-ROM development. Specifically, I will talk about the two main types of ROM spatial filters: the ROM differential filter and ROM projection. An important role played in ROM spatial filters and Reg-ROMs is the ROM lengthscale. In my talk, I will put forth a novel ROM lengthscale, which is constructed by leveraging energy balancing arguments. I emphasize that this novel energy-based lengthscale is fundamentally different from the standard ROM lengthscale introduced decades ago, which is based on simple dimensional arguments. Finally, I will illustrate the success achieved by ROM spatial filters and Reg-ROMs in under-resolved numerical simulations of the turbulent channel flow. Throughout my talk, I will discuss numerical analysis results proved for the Reg-ROMs that we propose, including fundamental properties, e.g., stability, convergence, and parameter scalings. I will also present some of the challenges and open questions in the development of rigorous numerical analysis foundations for ROM closures and stabilizations.