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

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Over the past decade, several closure and stabilization strategies have been developed to tackle the 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 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 two 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; and (ii) the Leray-ROM (L-ROM), which filters the convective term in the NSE. 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: (i) the ROM differential filter; and (ii) the ROM projection. I will also propose two novel higher-order ROM differential filters. 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 flow past a cylinder and turbulent channel flow.