CENTER FOR THERMO-FLUID MECHANICS

SPRING 2019 SEMINAR SERIES

Robust Modes in Hydrodynamic Flows

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WHEN: February 1, 2019 1:00 PM - 2:00 PM
WHERE: MREB ROOM 200
Multi-disciplinary Research and Engineering Building BLD#484

ABSTRACT

Analytical and computational studies of hydrodynamic and reacting flows are extremely challenging, due in part to nonlinearities of the underlying system of equations and long-range coupling. Moreover, accurate models of many of these systems in realistic settings are not available. Recent developments in high-resolution, high frequency experimental data capture offer an alternative approach to extract key features of the underlying states.

In this talk, I will introduce Koopman mode analysis, a nonlinear generalization of normal mode analysis, and dynamic mode decomposition, a computational method to extract Koopman modes from spatio-temporal data. The Koopman operator acts on any function of the state, such as a measurement, and expresses its evolution. Interestingly, this operator is linear in function space, independent of the nature of the dynamics in state space. The recently introduced dynamic mode decomposition permits an approximate evaluation of the Koopman operator. Eigen-functions of the Koopman operator are global structures, each of which evolve with a single complex growth rate. The analysis thus provides a decomposition of the flow into periodic constituents.

One issue elicited in the analysis of fluid flows is how noise and other irregular facets can be delineated from the "true" dynamics. Rather than addressing this directly, we recast the issue in terms of differentiating robust flow constituents (i.e., those common to nominally identical experiments) from non-robust features. Koopman mode analysis can be used to address the latter. I will illustrate the methodology using (1) cellular patterns on flame fronts, (2) instabilities in reacting flows behind a bluff body, (3) injector flows, and (4) swirling combustion.

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BIO:

Gemunu Gunaratne is a Professor and the Chairman of the Department of Physics at the University of Houston. He received his Ph.D. from Cornell University and conducted post-doctoral research at the University of Chicago before assuming the position at the University of Houston. He proposed the use of periodic orbits and their eigenvalues to characterize strange attractors and showed how dynamical invariants such as fractal dimensions and expansion rates can be derived from these eigenvalues. In spatio-temporal patterns, he invented a class of measures, referred to as the "disorder function," to quantify the level of pattern irregularity, and used them to describe the dynamics of pattern relaxation. He was a member of the "Chicago" group that first established anomalous scaling properties of hard-turbulence. Gunaratne's group analyzed "stylized facts" in financial markets, and showed that they follow from a stochastic process with variable diffusion. He has addressed several biologically related problems including establishing linear response as a possible means to establish the strength of osteoporotic bone and developing models to study animal locomotion. More recently, he has focused on model-free control algorithms for coupled networks and turbulent flows.