Department of Aerospace and Mechanical Engineering

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Numerical Simulation of Transition to Turbulence and Thermoacoustic Instabilities -- Analysis and Modeling

Thursday, February 6, 2014, 3:30P.M.

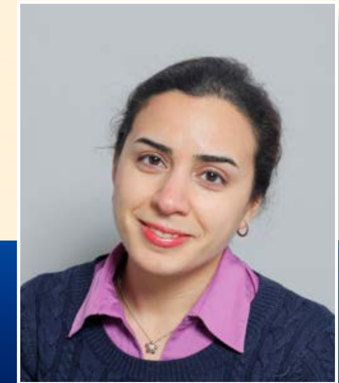
Lower Level Auditorium, Geddes Hall

Refreshments served at 3:00 p.m. in the Geddes Hall Coffee House

The flows encountered in relevant engineering devices are often turbulent, and therefore involve a vast range of spatial and temporal scales. This is the case in energy conversion systems, where a variety of complex phenomena such as transition, separation, combustion, and thermoacoustic instabilities occur. These phenomena are of different nature, and their intricate coupling makes their understanding and prediction particularly challenging.

Laminar to turbulent transition has been a subject of intensive experimental, theoretical, and numerical research. The accurate prediction of the transitional process impacts the design and performance analysis of engineering devices such as turbomachinery and flying vehicles. Direct numerical simulations (DNS) of Klebanoff (K-) type and Herbert (H-) type transitions are carried out for compressible (M = 0.2), zero-pressure-gradient flat plate boundary layers. Each calculation is performed using over one billion grid points, required to directly resolve the small scale turbulent structures in the near-wall region of the flow. These two calculations serve as a benchmark to assess the performance of predictive models. The modes of dynamical importance are extracted using dynamic mode decomposition (DMD). A few low-frequency modes are shown to provide a good estimate of the Reynolds shear stress gradient within the transitional region. This is of interest since large eddy simulation (LES) fails at predicting the rise to the overshoot of the skin-friction coefficient. The reduced-order representation of the flow is used to compare the LES and the DNS results within this region. The application of this methodology to the LES data illustrates the effects of the grid resolution and the subgrid scale model on the estimated shear stress associated with these low-frequency modes. The analysis shows that although the shapes and frequencies of the low-frequency modes are independent of the resolution, their amplitudes are underpredicted in the LES, resulting in the underprediction of the Reynolds shear stress.

During the conversion process, the unsteady nature of the transitional and turbulent flow can affect the performance of the subsequent stages. In the lean mixture regimes, encountered in combustion chambers, the interaction of the chamber acoustics, the flow unsteadiness, and the heat release rate can lead to self-sustained oscillations. These thermo-acoustic instabilities are notoriously difficult to predict and control. We introduce a dedicated solver applied to a modeled configuration, which enables the generation of accurate time series relevant to such systems. As opposed to frequency domain analysis typically used in this context, this approach is shown to capture linear and non-linear multi-modal dynamics.



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If you are interested in meeting individually with Dr. Sayadi, please contact Linda at 631-5431.