Center for Turbulence Research
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Hypersonics - overview

Six projects are included in this group. They range from formulations for studying fluid dynamical instability and transition to turbulence in hypersonic boundary layers, to schemes for studying the effects of detailed chemistry in high-Mach number shock tubes. Three articles address effects of chemical dissociation and reaction. The fourth considers flow phenonema, addressing the effect of high-temperature, non-equilibrium gas behavior on the flow over an isolated roughness element. This and the remaining two papers deal with instability and transition in high-speed flow.

Bourdon *et al.* evaluate N_2 dissociation rates versus temperature from first principles, using experimental measurements of the energy levels of vibrational states. The first principles rates are compared to existing empirical models. Agreement to other researchers' multi-temperature model is quite good at thermal equilibrium. The formulation of Bourdon *et al.* is able to capture strong disequilibrium; this is demonstrated through a computation of detailed chemistry in flow through a shock.

In the article by Graille *et al.*, Boltzman equations for neutral species, ions and electrons are used to model the statistical mechanics of reactive plasmas. A Chapman-Enskgog expansion is invoked to obtain reaction rates near thermodynamic equilibrium.

Thoemel *et al.* address an issue that arises in modeling heat shields exposed to hot plasma. The surface of the shield can be heated by catalytic reactions. In a thermal shield, catalysis takes place in small recesses on the rough surface. Thoemel *et al.* consider a cavity with bottom and side walls, bounded above by the flowfield, as a model geometry. This is characterized by an apparent catalytic activity. They find the apparent activity to increase with cavity depth, leveling off at about 20 times that of a smooth surface when the ratio of wetted area to opening width is about 50.

Birrer *et al.* invoke a 17-equation dissociation-recombination mechanism for high-temperature air. The geometry is flow over a wedge with a small roughness element. The specific geometry is that of the NASA HyBOLT experiment. Chemistry is included either in equilibrium or in non-equilibrium. Computations demonstrate that it is necessary to allow for non-equilibrium dissociation. Under equilibrium the flow is little different from the non-reacting case. However, non-equilbrium chemistry reduces the extent of the separation zones upstream and downstream of the bump and results in higher peak temperatures.

Groskpof *et al.* describe a two-dimensional, or bi-global, instability analysis. Their method is applied to a study of instability modes in the wake of a bump. Results for the cold flow are provided in this article, and for reacting flow in the article by Birrer *et al.*, both at $M = 4.8$. Streamwise vortices form in the lee of the bump. The vortices create low- and high-speed streaks. Groskpof *et al.* call symmetric modes y-modes and anti-symmetric modes z-modes. The z-modes are found to be the most unstable. They extract energy from the horizontal component of shear. In the case of cold flow, instabilities are found with about 4 times the growth rate of a T-S wave in the same flow without the bump. However, in reacting flow a lower growth rate was computed.

Durbin *et al.* develop a modal approach to inflow disturbance generation for DNS of hypersonic transition. An inflow disturbance can be represented by the complete set of linear modes. This requires both discrete and continuous spectra. Durbin *et al.* propose a treatment of the far-field condition that permits an association of the continuous eigenmodes with vortical, entropic and acoustic disturbances in the freestream. The mean shear couples vortical, entropic and acoustic components inside the boundary layer. Validation studies of a DNS code were conducted. They show how disturbances grow to a non-linear stage inside the boundary layer while being relatively unperturbed in the freestream.

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