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Status of the CROCCO Laboratory: Understanding and Predicting Turbulent Hypersonic Flows

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Abstract
Progress is being made in the advancement of basic knowledge and predictive capabilities for turbulent hypersonic flows. For the first time, experiments and computations are being performed at the exact same conditions for a one-to-one comparison. As part of the research, an open database of traceable, standardized hypersonic turbulent flows is being established. A modular and efficient infrastructure is being developed so that researchers outside the Crocco Lab may be able to access the database and simulation tools to advance knowledge, data-mining techniques, and simulation procedures in fluid mechanics and other related fields. In the proposed talk, I will describe how these techniques are being integrated to develop accurate turbulence models.

Progress Report

I founded the Crocco Laboratory in Princeton University the summer of 2002. The laboratory is composed of four Ph.D. students, an undergraduate student, a lab technician, a dedicated PC cluster with 0.5 teraflop capability, a RAID system for data storage, in-house developed simulation procedures, and myself. The on-going research includes the development of basic knowledge and predictive capabilities for turbulent flows in chemical nonequilibrium. Such a capability does not currently exist and is essential for the design of efficient hypersonic systems. In this regard, the research in the Crocco Laboratory includes theory, simulation and collaboration with experimentalists to develop a basic understanding of the physics behind the interaction of chemical reactions and turbulent flows. Based on the new understanding, the group develops efficient simulation models that accurately represent the flow physics. In addition, we are establishing an open database of traceable, standardized hypersonic turbulent flows. The database includes experimental and computational data. For the firs time, these experiments and computations are being performed under the exact same conditions for a one-to-one comparison. The data and predictive capabilities are being integrated into a Modular and Efficient Scientific Computing Infrastructure (MESCI) that will be remotely accessible. The first version of MESCI was successfully implemented this summer (E. Deckter, K. Schreer, B. Kernighan, and P. Martin). Accordingly, the ongoing research will provide:

1. Improved knowledge of hypersonic aerodynamics and aerothermodynamics in the turbulent regime.

2. Accurate physical models for the prediction of turbulent hypersonic flows in dynamic and thermo-chemical nonequilibrium.
3. Efficient simulation capabilities to predict the characteristics of the flows of interest.
4. A well-documented experimental/computational database of turbulent hypersonic flows.

The goals of the on-going research are being accomplished via accurate data analysis and simulation of canonical flow configurations at typical hypersonic conditions using direct numerical and large-eddy simulation, DNS and LES respectively. These configurations include turbulent boundary layers with and without adverse pressure gradient; shockwave/turbulent boundary layer interaction configurations; and flow around axisymmetric and elliptical cross-section cones. Effects of Mach number, wall-temperature conditions, and chemical reactions, as well as the effect of boundary conditions, numerical treatment of the governing equations, and simulation procedures are being studied. Also being conducted are analyses of the mean flow, flow structure, turbulence fields, and energy transfer mechanisms. A key feature of these simulations is validation against experimental data under the exact same conditions. Data is being obtained from experimentalists in Princeton University and California Institute of Technology. In this regard, data-mining and post-processing techniques are being developed to make accurate comparisons between the simulation and experimental data.

During my talk, I will use representative canonical flow configurations to illustrate the physical phenomena that we are studying. I will also give a progress report on how the results from experiments, DNS and LES are being integrated to gain understanding and to develop accurate predictive tools and how these will be accessible to the scientific community.