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Progress of Simulations for Reacting Shear Layers

Sheng-Tao Yu

1. Motivation and Objectives

In the past six months, the effort was devoted to the development of a high speed, chemically reactive shear layer test rig. The purpose of the experiment is to study the mixing of oxidizer and fuel streams in reacting shear layers for various density, velocity, and Mach number. The primary goal is to understand the effects of the compressibility upon mixing and combustion in a fundamental way. Therefore, a two-dimensional shear layer is highly desirable for its simplicity to quantify the compressibility effects.

The facility consists of a two-stream wind tunnel with two independent gas supplies. After passing through flow-management devices located upstream, each gas stream expands to its predetermined Mach number by means of a contoured center body and tunnel walls. Various combinations of flow conditions of high-speed stream and low-speed stream allows for the systematic study of mixing and reactions of compressible shear layers.

2. Work Accomplished

The RPLUS 2D code is used to calculate the flow fields of different sections of the test rig. The emphasis was on the supersonic nozzle design, the vitiation process for the hot air stream and the overall thermodynamic conditions of the test matrix.

The $k - \epsilon$ turbulence model with wall function has been successfully implemented in the RPLUS code. The k and ϵ equations are solved simultaneously and the the LU scheme is used to make it compatible with the flow solver. The coupling between the flow solver and the $k - \epsilon$ solver depends on the turbulence viscosity only, and the $k - \epsilon$ solver is separated from the flow solver to reduce the complexity. The newly developed code has been used for the compressible shear layer calculations. Many cases of the compressible free shear layer with various convective Mach numbers and density ratios have been simulated using the compressible $k - \epsilon$ solver. The results are summarized in two technical papers.[5,6] Currently, the $k - \epsilon$ solver is a standard feature in the RPLUS 2D code and the code has been distributed to the industry and universities through NASP group. Locally, Duncan and Tsai are using the $k - \epsilon$ solver for their research work.

3. Future Plans

Physical phenomena of the reactive free shear layer can not be adequately described by the $k - \epsilon$ model coupled with the Reynolds averaged flow equations. The properties of the vortical flows which dominate the whole flow field of free shear layers can only be illustrated by time marching numerical method with accurate spatial resolution. Traditionally, the spectrum methods were used for this kind of applications. However, very limited success has been reported for compressible flows using spectrum methods. On the other hand, recent development show promising results using high order central differencing and Essentially Non-Oscillatory (ENO) schemes. One developed by Lele of Stanford university using high order compact differencing is especially interesting. Future work includes Direct Numerical Simulation (DNS) of Navier Stokes equations for the chemically reactive flow and application to free shear layers.

In additional to the above mentioned work, I will serve as a consultant for the $k - \epsilon$ solver in the RPLUS code.

4. Publications

1. S. T. Yu, J. S. Shuen, and Y-L P. Tsai, "Three Dimensional Calculations of Supersonic Combustion Using a LU Scheme," to appear in the J. of Comput. Phys.

2. S.T. Yu, C.L. Chang, and C.L. Merkle, "Solar Rocket Plume/Mirror Interactions, " submitted to the J. of Spacecraft and Rockets.

3. S.T. Yu, B.J. McBride, K.C. Hsieh, and J.S. Shuen, "Hypersonic Flows Simulations with Equilibrium or Finite Rate Chemistry," submitted to Computers & Fluids for publication

4. S.T. Yu, "A Convenient Way to Convert 2D CFD Codes to Axisymmetric Ones," submitted to J. of Propulsion and Power as a technical note.

5. S.T. Yu, C.D. Chang, and C.J. Marek, "Modern CFD applications for the Design of a Reacting Shear Layer Facility," presented at the AIAA Science Meeting, 1991.

6. S.T. Yu, C.D. Chang, and C.J. Marek, "Simulation of Free Shear Layers Using a Compressible k-ϵ Model," accepted for presentation at the AIAA Propulsion Conference, 1991.