Center for Modeling of Turbulence and Transition
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Turbulence Modeling in Supersonic Combusting Flows

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1. Motivation and Objectives

To support the National Aerospace Plane project, the RPLUS3D CFD code has been developed at the NASA Lewis Research Center. The code has the capability to solve three dimensional flowfields with finite rate combustion of hydrogen and air. The combustion processes of the hydrogen-air system are simulated by an 18-reaction path, 8-species chemical kinetic mechanism. The code uses a Lower-Upper (LU) decomposition numerical algorithm as its basis, making it a very efficient and robust code. Except for the Jacobian matrix for the implicit chemistry source terms, there is no inversion of a matrix even though it uses a fully implicit numerical algorithm.

The main purpose of this work is to incorporate a k-ϵ (two equation) turbulence model into the RPLUS3D code.

2. Work Accomplished

Since February 1990, when this work was started, some of the more important accomplishments are categorized as follows:

1) Add a k-ϵ turbulence model: The model selected is in a high Reynolds number form. The low Reynolds number form could not be used economically in the case of a three dimensional flow with chemical reaction since it demands too much in computer resources. The addition was designed to be as modular as possible but some interactions with the main code are needed in order to be more efficient. The first test case tried was a Mach 0.5 flow over a flat plate. The velocity profile compare very well with the log-law profile. The friction coefficient also compares well with the Van Driest correlation. More validations will be performed for other flows such as free shear layer and jet flows.

2) Improved accuracy and convergence rate: According to a stability analysis of a model equation, it is shown that the RPLUS3D code excessively added artificial damping to the right hand side of the algorithm while at the same time it overestimated the spectral radii on the left hand side. These excessive additions would not give an optimum convergent rate. Mod-

ifications were made such that true directional spectral radii were added to the left hand side and the artificial damping terms were reduced to optimum values in accord with the stability analysis.

A test run was made of a Mach 4 flow of air over a 10 degree compression ramp. It was found that the modified code converged to machine zero about five times faster than the original code while at the same time it somewhat improved the shock resolution.

3) Added consistent damping terms at block interfaces: It had been observed that at the block interface of a multi-block grid, wiggles developed. This happened because the damping terms at the interface were not consistent with those at the interior points.

4) Validated RPLUS3D with laminar flows over flat plates: The test cases run were for Mach numbers of 0.1, 0.3 and 0.5. Results of all cases seemed to be good except for the region of high curvature of the velocity profile near the edge of the boundary layer.

5) Add two dimensional capability to the code: It turned out that this is not a trivial task especially for a finite volume code like RPLUS3D. It is nice that now the code can solve a 2D flow without having to carry the 3rd direction along as a redundancy. There is, of course, no need to maintain a separate 2D code.

6) Implemented a local time stepping capability: The original code always ran at a fixed time step of 1 second. For most flows this corresponds to using a very large CFL number which may not be conducive to a fast convergence rate. With the local time stepping, it was found that an optimum CFL number was, in agreement with other investigators, around 5 to 7.

7) Implemented implicit boundary conditions: This addition enhanced the convergence rate by about 30 percent at the expense of a more complex code and an increase of about 20 percent in CPU time per iteration step. There seems to be, then , no net advantage of the implicit boundary condition except maybe in the area of robustness.

8) Changed input file: Instead of having to scan a whole subroutine to set up a problem, a user now can change numbers in a small file of length about one page. To start up a run from a previous run one now needs only to change a parameter in this input file without having to recompile the input subroutine as before.

9) Solved two 3D hypermixing flow fields of W.Hingst and D.Davis: This work was performed in collaboration with Dr. A.C. Taylor of Old Dominion University. My task was to set up the program for these particular problems

and to generate the grid for one of the problems.

3. Future Plans

The work plan for the year 1991 consists of both basic model implementations and practical applications of the code :

- Continue to validate the baseline k-ϵ model.
- Add compressibility effects to the base line model.
- Apply the base line model to re-solve the 3D flowfields mentioned in the previous section.