590941
P.6

Final Report

A Unified LES/RANS Approach Using the CE/SE Method

Principal Investigator: William W. Liou, Ph.D.
Associate Professor
Mechanical and Aeronautical Engineering
Western Michigan University

Issued by : NASA Glenn Research Center
Cleveland, Ohio

Grant Number: NAG3-2529

Award Duration: January 18, 2001- January 17, 2002

Technical Officer: Sin-Chung Chang
MS 5-11
NASA Glenn Research Center
Tel.: 433-5874

Objectives

The goal of the proposed research is to develop advanced large eddy simulations (LES) and Reynolds average Navier-Stokes (RANS) capabilities for complex problems using the conservation element and solution element (CE/SE) method. This proposed use of the CE/SE method is justified by the many demonstrated advantages of the CE/SE method over the traditional computational fluid dynamics (CFD) methods. The proposed research will produce improved engineering modeling for near-term applications for focus programs as well as long-term impacts on the fundamental understanding of turbulence.

Background

As was described in the previous progress report (November 20, 2001), laminar boundary layers and free mixing layers were to be used to benchmark the versions of the CE/SE code developed by the CE/SE group. Discussions with the group indicated that efforts were underway to improve the implementation of the solid-wall boundary conditions and there were suggestions that LES of wall-bounded flows be performed at a later time. As a result, we have performed preliminary calculations of high-speed mixing layers as a first validation case when the parallel computer cluster in the Computational Fluid Dynamics Lab becomes operational in the last quarter of the funding period. Detailed description of the cluster (CEPCOM) has been included in the previous progress report. The CE/SE codes were first adapted to the CEPCOM parallel computing environment. We appreciate the quick responses of Dr. X-Y. Wang to our many calls for help in the effort to get the pervious as well as a new version of CE/SE code to work on CEPCOM. The flows with shock/boundary layer interaction reported by the group (X.-Y. Wang) were calculated for benchmarking and the results agreed with those published in Dr. Wang's previous publications.

In the following, our initial results of the free mixing layer calculations are described. The effects of numerical dissipation are examined by comparing the results with those obtained by using the first-order upwind (UD1), a third-order compact upwind (CUD3) and a fifth-order compact upwind (CUD5) schemes.

Supersonic Mixing Layer Results

Figure 1 shows the development of the thickness of a laminar mixing layer of velocity ratio 0.786 and a high-speed stream Mach number of 1.9. Numerical studies and experimental data on a turbulent mixing layer at the same operating conditions have been reported and can be used to validate our future LES results. Figure 2 shows the velocity profiles at the various streamwise stations in a self-similar coordinate for Reynolds number of 2075. The velocity profiles collapse indicating that the flow is self-similar. Calculated flows with various other different speed ratios exhibit similar behavior. Note that a hyperbolic-tangent type of distribution, which is a self-similar analytic solution for laminar mixing layers, has been assumed for the inlet velocity in these cases and the results in Figure 2 indicate that the CE/SE solver is able to preserve the analytical self-similarity in its numerical operations.

An important factor to consider in LES is the numerical dissipation. As the SGS model provides the means of energy transfer between the resolved and the unresolved scales of fluctuations, numerical dissipation apparently plays a similar role in LES. It is of paramount importance for LES that effects of numerical dissipation are insignificant compared with that of physical meanings. For many schemes, it is difficult to quantify numerical dissipation. The numerical dissipation in the CE/SE method can be related to a single parameter. In order to compare the significance of the numerical dissipation in the CE/SE method with other higher-order schemes, we have developed and validated a new Navier-Stokes code employing the first-order upwind (UD1), a third-order compact upwind (CUD3) and a fifth-order compact upwind (CUD5) during the grant period. The code was used to calculated laminar mixing layers.

Figure 3 shows the results for the same laminar mixing layer as that for the previous figures. The solid markers and the corresponding symbols represent the changes of the mixing layer thickness obtained with and without the viscous terms, respectively. The value of the numerical dissipation parameter was set at 0.5 for the CE/SE calculations. Note that there was no "disturbance" forcing applied at the inlet. The inlet velocity profile and the size of the computational domain are such that we do not expect any perturbation generated by the numerical operations be picked up by the inviscid hydrodynamic instability mechanisms. As a result, it can be argued that any increase of the lateral size of the region of mixing would be due to the numerical dissipation in the absence of the viscous terms. As expected, the UD1 result, with large numerical dissipation, shows a growth of the thickness significantly higher than UD3, UD5 and CE/SE. The inclusion of the viscous terms in UD1 does not change appreciateably the results, indicating that the numerical dissipation of UD1 has overwhelmed the physical dissipation even at this relatively low Reynolds number. The inviscid results obtained by using UD3 also show a growing mixing layer thickness. The inviscid CUD5 and CE/SE results show little or no growth in the thickness, indicating a negligible effect of numerical dissipation. Even with the viscous terms included, the CUD5 and CE/SE results still show a rate of growth smaller than that of the inviscid CUD3 result.

While it is difficult to devise a measure for numerical dissipation, for the simple mixing layers, parameters such as rate of growth may be used to correlate the order of magnitude of numerical dissipation, perhaps, through Reynolds numbers. This may then be used as a guide to estimate the relative significance of numerical dissipation and SGS models in LES using CE/SE.

Although the preliminary results obtained in the limited one-year grant period does show the merits of using the CE/SE method for LES compared with prevailing numerical schemes as conjectured in the proposal, we have yet to demonstrate the full potentials of its use in LES. Further activities may include the flows traditionally studied using LES and flows that prevailing LES schemes have not been able to tackle.

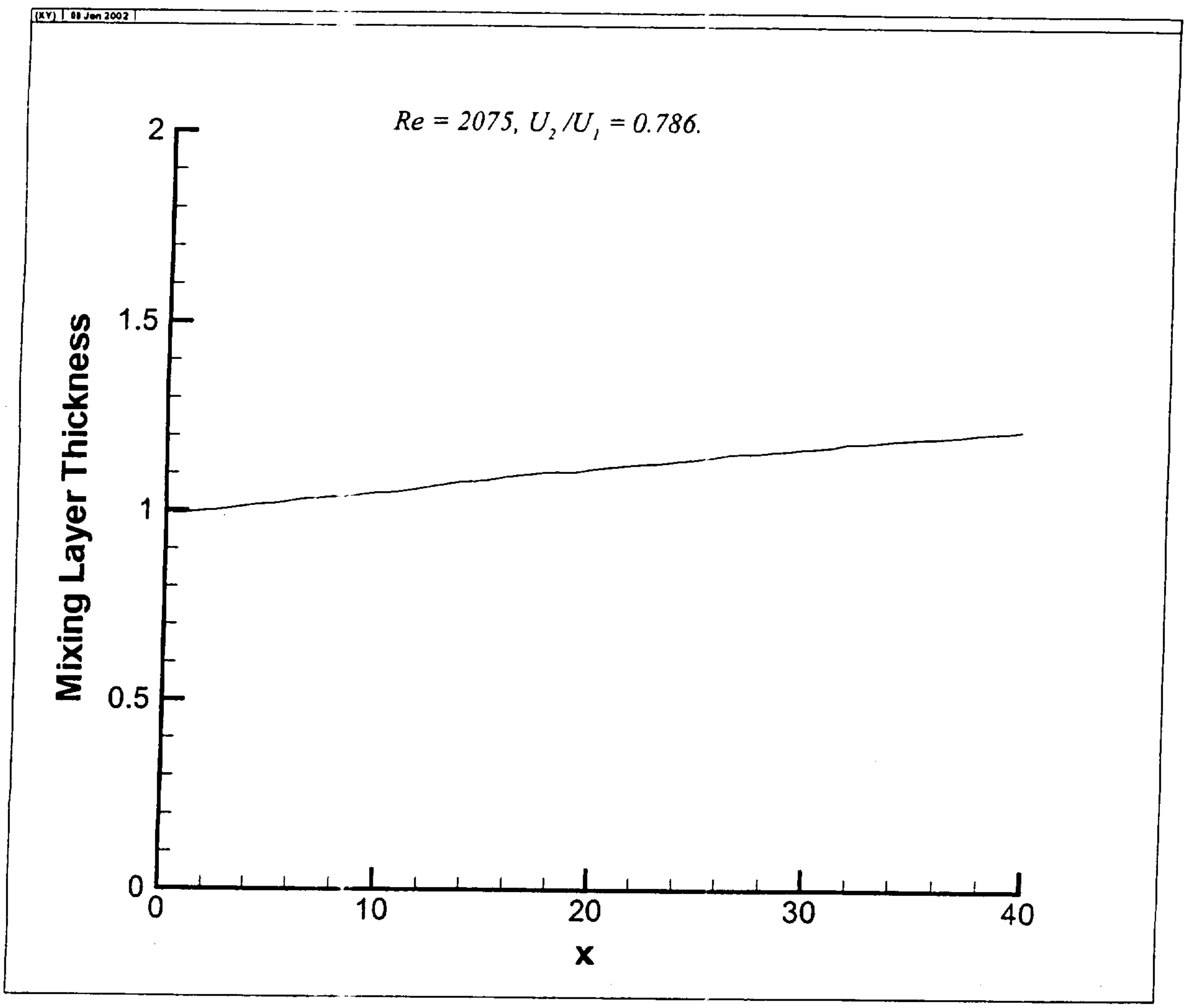

Figure 1. Thickness of the mixing layer.

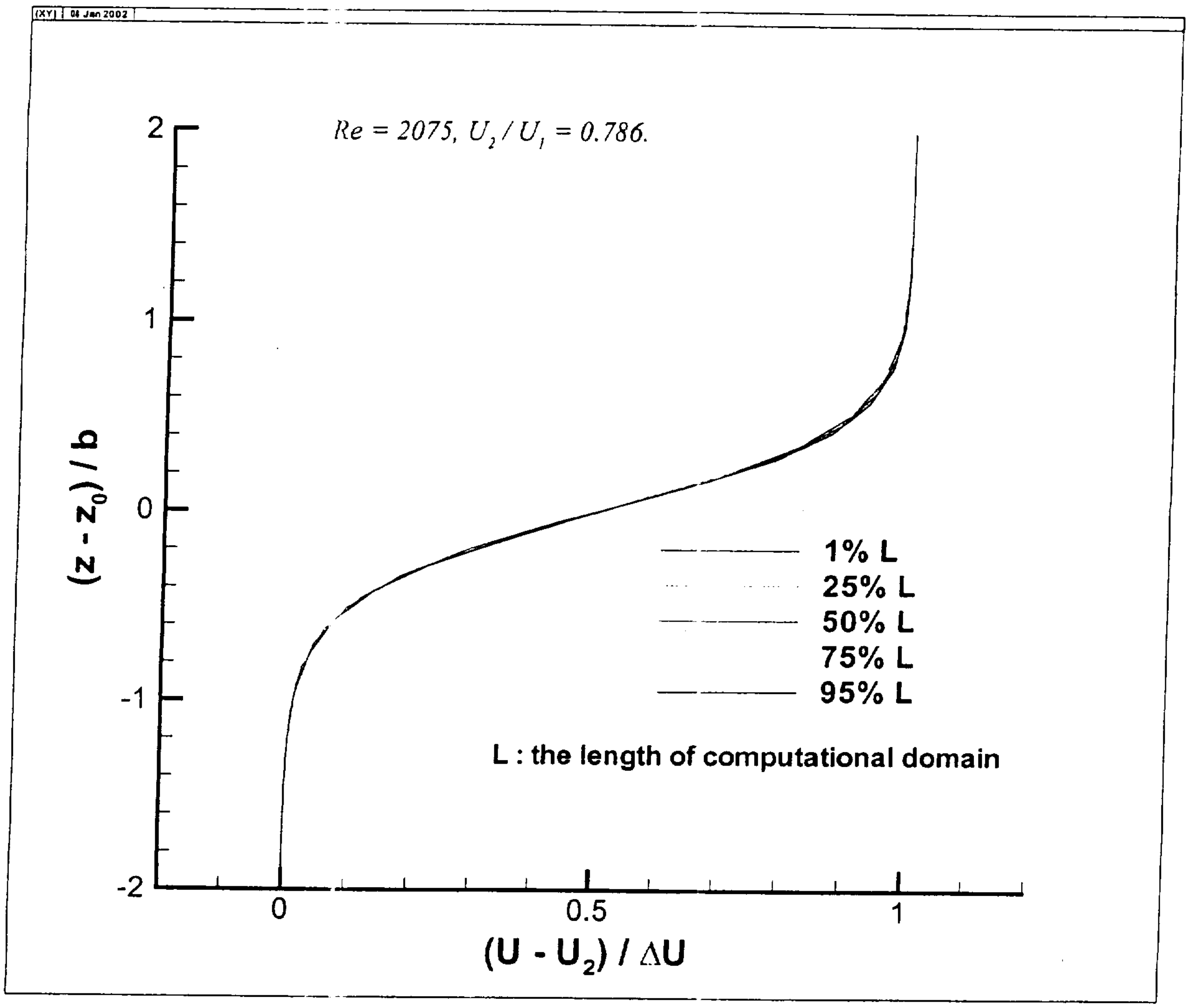

Figure 2. Streamwise velocity profiles.

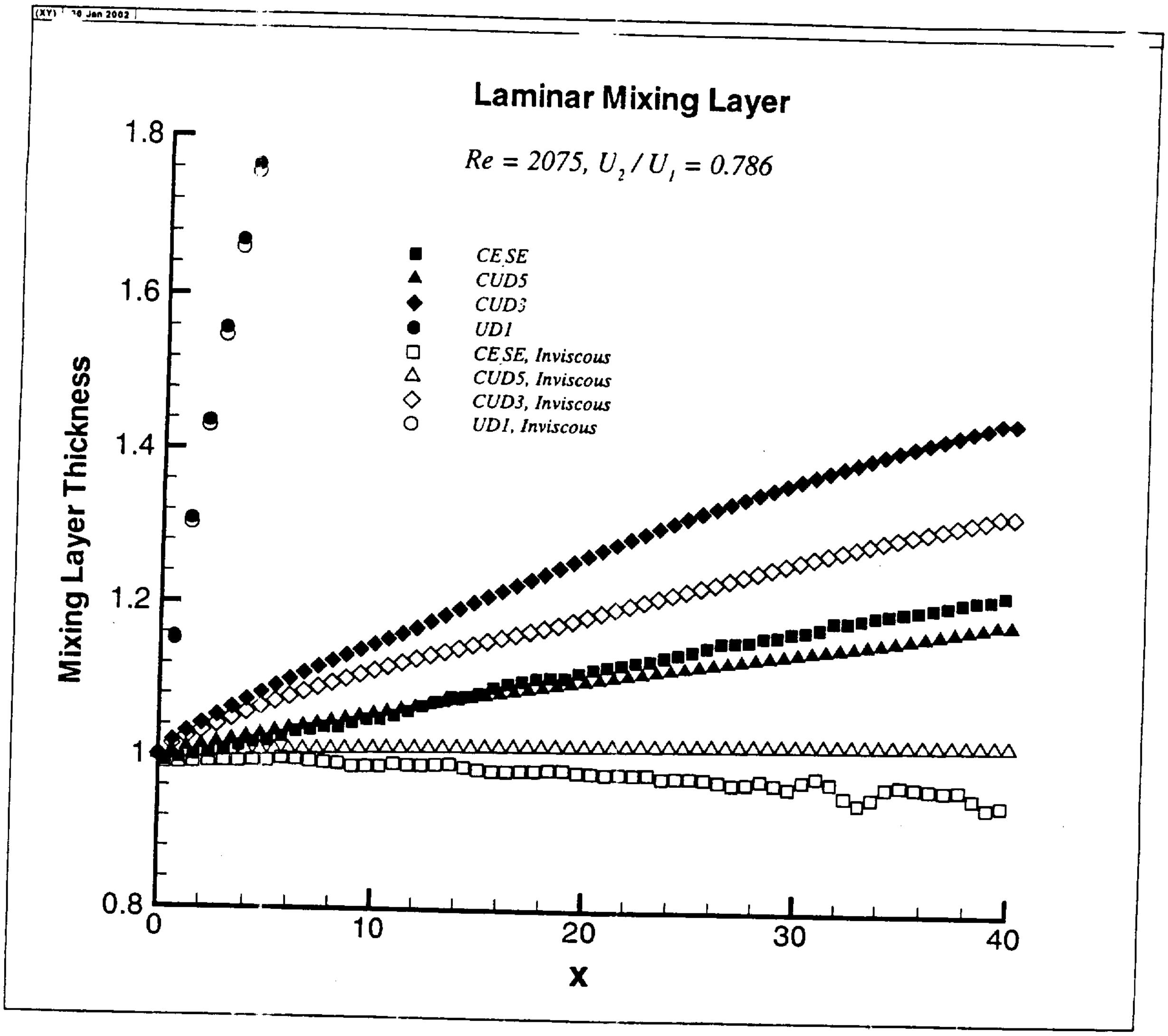

Figure 3. Comparison of streamwise thickness variation.