Discussion

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General Description

Eight groups participated in the Workshop, with varying degrees of completion of the Workshop problems. The problems consisted of two main categories: (1) turbulent flow over a flat plate with exact solutions produced by the Workshop organizers using the Method of Manufactured Solutions (MMS), and (2) a physical problem from the ERCOFTAC data base for turbulent flow over a backstep. Both categories included several possible turbulence models, and participants used a variety of discretization schemes and grids, and some variation in the uncertainty estimators.

Executive Summary and Future Plans

Briefly, (1) the results for the Manufactured Solution test cases provided another significant positive evaluation of the Grid Convergence Index for uncertainty estimation, both in its basic grid triplet and least-squares forms, for all turbulence models and discretization methods tested, and (2) the results for the physical problem, while generally consistent and not negative, did not provide conclusive results because of differences in models and uncertainty estimators, and especially because of general failure to achieve sufficient grid resolution to assure that the calculations were in the asymptotic range.

The current plans for Lisbon III in 2008 include a requirement to consistently evaluate the uncertainty estimators by requiring high resolution calculations for each submission, while not requiring uniformity of modeling assumptions for each contributor. Evidence of Code Verification will again be required using a Manufactured Solution, but a participant will be able to use a case already calculated for Lisbon II, so that no additional work would be required for repeat participants.

More Detailed Comments

The results of the eight groups for the MMS problem were very positive, consistent with the target of 95% certainty on the error bars. Two of the eight groups are not considered here. Group #3 (EPM) used solution-adaptive grid generation and a single-grid error estimation technique rather than an uncertainty estimator approach. Nevertheless, their results were very high quality. Especially noteworthy was the ability to obtain error estimates for local and functional quantities with a single-grid error estimator. Group #4 (WVU) used pseudo-laminar calculations, i.e. all the turbulence terms were grouped into the source term on the RHS. The velocity profiles are representative of turbulent flow rather than laminar, so the error estimation is more demanding than a simple laminar flow. However, the discretization errors do not arise from discretization of turbulence terms, as in a real problem, so the results are not considered to be of fundamental interest. (Nevertheless, the uncertainty estimates obtained by Group #4, while large, do appear to be successful, i.e. conservative.) Most of the contributed results, and the most thorough study, came from Group #8 (IST/MARIN).

A perusal of all the error bars presented for the MMS provides a positive evaluation of the uncertainty estimators used. As expected, convergence is better behaved and uncertainty estimates are more reliable for integrated functionals (e.g. total skin friction drag) than for local quantities. Some of the very high resolution results of Group #8 could not be evaluated graphically, i.e. the error bars and the error level were so small that a near 0/0 indeterminacy resulted. That is, the error bars may or may not be smaller than the true error, but for all practical purposes (practical for real turbulent flows of engineering interest) the uncertainty evaluation was not of interest because the error was so insignificant.

For the Manufactured Solution problem, of the other 96 cases (all groups) of practical interest, 94 incidences gave conservative error bars. Some of these conservative cases were "near misses", but then so were the 2 non-conservative cases. Overall, this result is consistent with the target goal of 95% certainty in the error bars, and with the several hundred previously evaluated CFD cases, providing further evidence of the methodology and the empirical Factor of Safety (Fs) used. Although the 96/98 conservative cases give a (literal) error bar coverage of 98%, any distinction between this and the target 95% is not warranted statistically. (In fact, rather than indicating that the recommended Fs is slightly too conservative, the results could be interpreted the other way, bearing in mind that the Workshop results are skewed by the disproportionate participation of the IST/MARIN group whose exacting work is probably atypical of common practice.) Also, the present results span five turbulence model variations. Thus, further fine-tuning of Fs is not considered worthwhile for this family of "nearby" problems.

The results for the physical problem of turbulent flow over a backstep were not as conclusive as hoped. No real shortcomings with the uncertainty estimation methodologies were displayed, but there was more variation in the modeling than desirable. Most importantly, the grid resolutions used, while representative of common practice, failed to achieve the asymptotic range, as demonstrated by the thorough work of the IST/MARIN group. Not all of these results provide evaluation of the GCI. In many of the IST/MARIN results the observed convergence was either (a) monotone with p outside the range [0.95, 2.05], or (b) oscillatory, in which cases *ad hoc* uncertainty estimates were used involving the range of results. Likewise, Group #1 (ECN) used a different uncertainty estimator. Thus the results for the backstep problem provide a sampling for candidate uncertainty estimators (some preliminary) used in, or proposed for, current practice rather than a consistent evaluation of a single method.

Nevertheless, an overview presentation of the results on the backstep problem, including those from Lisbon I, show an encouraging consistency. While there is some variation in the solutions due to modeling and numerics, the error bars obtained by several different methods appear realistic and generally consistent. Complete overlap cannot be expected, due to modeling discrepancies (i.e. turbulence models, boundary conditions).