Perspective on the 2nd Workshop on CFD Uncertainty Analysis

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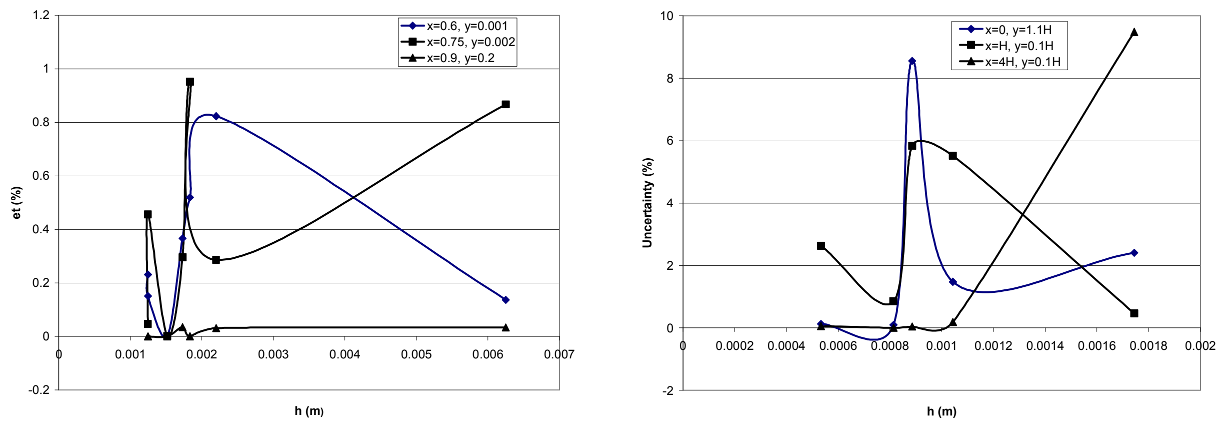
After an illuminating experience from the first workshop I had hoped that 2nd workshop will sort out some good and bad error estimators because of the emphasis on manufactured solution. I can not say that this objective has been accomplished at the 2nd Workshop, in spite of; I must point out, many useful and enlightening exercises presented by many prominent participants. I had expected, at least for the boundary-layer type of flow, various error and uncertainty estimating methods be compared and an assessment made as to the performance of these methods. In a way, my expectation was that this workshop would be the ***verification of the verification methods*** by way of manufactured solutions. Now, I have to hope that the 3rd workshop will address this issue. Since there is very little hope we would ever get fully converged or grid independent solutions for more realistic engineering problems such the flow over a complete full-scale ship-hall, it is essential that error and/or uncertainty estimators be verified and their performance, especially on relatively coarse grids, be assessed. When the grid is very fine the errors are small. For example for the manufactured solution case, on fine grids, the true error is in the order of 0.5 % or less (see Fig. 1a). In case of backward facing step the uncertainties are less than ca. 3 % (errors should be even less) (Fig. 1b.) These are negligibly small errors for practical engineering applications. The strength of the error estimators should be their ability to give reliable uncertainty on relatively coarse grids. That is where the need is. In this regard I suggest the following pathways:

(1) Develop manufactured solutions to Navier-Stokes equations for more complex problems with the constraint that every term is exercised at least in different regions of the flow domain. Use these solutions to develop reliable error estimators on relatively coarse grid.
(2) In the mean time develop criteria that can be used to determine whether a given grid is “coarse” or “fine” for a given problem. If one can not tell where the asymptotic range is with regards to Richardson extrapolation the method losses its viability.
(3) Perform calculations on a problem with relatively easy boundary conditions and require all users to implant these boundary conditions as closely as possible. Then ask all participants to perform a systematic grid convergence study. The results that are proven to exhibit good convergence can then be used to assess the performance of different error estimators. The deviations among various participants solving the same equations with seemingly the same boundary conditions should be considered as part of the uncertainty. I do not know how to call this, implementation error, user error or modeling error. What ever they are, the results from the 2nd workshop seem to indicate that such deviations are fact of CFD world and they are inevitable.

Finally I would like to point out my own frustration with the Richardson extrapolation methods: unknown asymptotic range, oscillatory convergence, and unreasonable apparent order of convergence are a few of them. It is time that we accept these deficiencies and do not pretend that Richardson extrapolation is the recipe for all verification problems. I would like to encourage all participants to explore other error estimators on two grids and possibly on single grid with the goal that the error estimated on relatively coarse grids are reliable in the sense that they are not much further than the true error, ideally bounding it with a reasonable confidence interval. Having said that, I am aware of the good old American saying "There ain't no free lunch!". To succeed we have to pay the price one way or the other.



(a) (b)

Figure 1 (a) Relative true error in axial velocity at three different locations for the case with manufactured solution; (b) Uncertainty in axial velocity at three different locations for the backward facing step case: The data is taken from different participants compiled in the proceedings. The grid parameter is estimated as the average cell size, $h=(A/N)^{1/2}$; A= area of the computational domain and N is the number of computational cells.