Beyond Lisbon Workshops on CFD Uncertainty Analysis

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The three workshops on CFD Uncertainty analysis organized by Eça and Hoekstra were only the beginning, not the end! Despite the many successes, the results from these Workshops have clearly demonstrated that there are still many challenging problems to be resolved in the area of error and uncertainty estimation in CFD applications. Here are some of these:

(1) When a code verification is completed satisfactorily, should one assume that subsequent solutions using that code will always exhibit grid convergence? That is, will it satisfy Lax's equivalence theorem (in the sense that a stable and consistent scheme is also convergent)?

(2) Is oscillatory convergence as observed in a converging series such as $E = ah^p \cos(\omega h)$, p>0, an acceptable convergence behavior? If so how can it be identified without determining the frequency ω? If not, how many simulations are needed to determine the apparent order p, the amplitude, the frequency ω, and the extrapolated solution?

(3) When do we know that a certain grid resolution is in the asymptotic range? Note that if the convergence is truly oscillatory one needs to keep at least two terms in the asymptotic range.

(4) What is an acceptable grid refinement, especially when non-structured grids are used with selective or adaptive grid refinements?

These challenging issues can only be resolved by having competing methodologies evaluated against well defined and thoughtfully designed bench marks. These can be experiments planned and conducted in parallel with CFD simulations. They can also be selected from existing or future well resolved LES (large eddy simulations) or DNS (Direct Numerical Simulations), but also they can be analytical solutions carefully formulated with the help of the method of manufactured solutions. In DNS and well resolved LES no wall functions are used. In LES the magnitude, and in most cases, the significance of the modeling contribution decreases as grid is refined. Detailed information on inlet and boundary conditions, which are very difficult to obtain from experiments, as well as most turbulence statistics such as Reynolds stresses that are needed in RANS (Reynolds Averaged Navier-Stokes) modeling can be extracted directly from these simulations. Extracting length scales and/or turbulent dissipation rates can be somewhat difficult (see Celik et al, 2008), but then these simulations need also be designed with CFD validation in mind.

It was encouraging to see that even during the two year intervals of the three workshops held in Lisbon there has been a number of new methods proposed, in addition to modifications to older versions of error and uncertainty estimation methods. While some of the participants were testing the least squares based approach proposed by Eça and Hoekstra in the previous workshop, the authors of this same method themselves were

already proposing new modifications to the older version of their own method. In the mean time, Hay and Pelletier came up with a new way of error estimation that is applicable with unstructured adaptive grids. Celik and co-workers also proposed a new methodology based on Approximate Error Scaling (AES) concept that is promising in some respects. I find these encouraging and positive developments. I believe that the future workshops will, and should rightly so, focus on more validation exercises for newly emerging error and uncertainty estimators. We should encourage and support these activities and let a thousand ideas flourish and compete in arriving at the best ones. The recent history of the development of turbulence models is a good example of how much research and how much time will be needed to make a break through. We should be prepared for a long and rough road in the development of reliable error and uncertainty estimators in CFD applications. I am optimistic in this regard.

I congratulate and thank the organizers of the Lisbon Workshops and wish that they will continue such efforts if not under the same name and same place, under different names and different places, using different opportunities.

Reference:

Celik,I. Klein,M. and Janicka,J., "Assessment Measures for Engineering LES Applications'', ASME Journal of Fluids Engineering, in press, March 2009.