Journal of Fluids Engineering

Editorial

RANS/LES/DES/DNS: The Future Prospects of Turbulence Modeling

While we were discussing the rapid increase in Large Eddy Simulation (LES) papers submitted to the Journal of Fluids Engineering (JFE) several years ago, Joe Katz, the editor in chief of JFE, suggested that we needed to organize more in depth symposia to sieve through LES papers as well as to educate the newly emerging large groups of LES users in almost all areas of engineering applications. We also talked about coming up with some sort of a quality assessment criteria to make a judgment of the overall quality of papers that were claimed to be LES. That is where the idea of publishing a special issue on mostly LES applications was started. This special issue is mostly the end result of that discussion. With the hard work of all of the individuals listed in the acknowledgments, we have successfully organized a symposium on "Advances and Applications of LES/DNS." More than 40 papers were submitted. After a thorough review process, 24 papers were accepted to be presented at the symposium held as part of the Joint Fluids Engineering and Heat Transfer Summer Conference, June 11–17, 2004, Charlotte, NC. These papers were further thoroughly reviewed for publication in this special issue according to the standards of JFE. Finally, 13 full papers and one technical brief were recommended for publication.

It was difficult to categorize the papers in this issue into specific classes, though we have tried to order them roughly so that they start with more general review papers and more fundamental topics then proceed towards more applied research papers. Since the fashion for LES was so popular, we wanted to explore first what was going to happen to the good old Reynolds Averaged Navier-Stokes (RANS) models. The first paper by Hanjalic attempts to answer this very question. It should be viewed more as a perspective from a prominent individual who has devoted his carrier spanning close to half a century to development of classical turbulence models. Recent assessments have shown (see, e.g., Rodi [1], Froehlich and Rodi [2], and Temmerman et al. [3]) especially for wall bounded turbulent flows, that a good LES is almost a DNS. That is, a proper resolution of wall layers and prediction of transition to turbulence in boundary layers requires extremely fine grid resolution. For that, one has to resort to some sort of wall functions, and/or a RANS model to save time and perform calculations in an acceptable turn around time for practical engineering applications such as flow around ship hulls. That requires inevitably a hybrid LES/RANS or DES approach. That, in turn, requires a good RANS model. Moreover, even a very crude RANS turbulence model seems to do a good job as a subgrid scale (SGS) model in LES (see Ref. [4]).

SGS models constitute a major component of LES calculations. It is shown by Chen et al. [5] (see also Meneveau et al. [6]) that the balance of predictive capability may change when the stress-strain relationship becomes convoluted under transient rapid straining/destraining conditions. Their a priori analysis indicates that in some cases the dynamic Smagorinsky model does not perform as well as the classical Smagorinsky model, contrary to past experience and expectations. This, therefore, points towards the need to perform more experimental and numerical work to assess the performance of SGS models in more complex engineering flows that exhibit high turbulence Reynolds numbers, rapid straining/destraining, and curvature effects.

LES papers presented in this issue show that, in general, LES results in better agreement with experiments compared to RANS if the grid resolution is sufficiently fine. However, it is difficult to assess without a priori knowledge of the flow characteristics, what grid resolution is actually "sufficient." To this end there need to be some quality assessment measures. Although not part of the special issue, the paper by Celik et al. [7], also printed in this issue, tries to address this question by formulating a LES index of quality (LES_IQ). Some other recent studies (Klein [8], Guerts [9], Meyers et al. [10] and Celik et al. [11]) have also attempted to quantify errors involved in LES calculations. The work by Guerts et al. [9] shows clearly that modeling errors and numerical errors can have opposite signs in some flow regimes, thus indicating a good performance on coarser grid resolutions, but can worsen as the grid is refined while keeping the filter size used in the SGS model fixed.

Several papers fall into the category of detached eddy simulation (DES) or similarly hybrid RANS/LES. The papers by Paterson and Peltier, Wiswanathan and Tafti, and Saric et al., elucidate the critical issues in this approach. The main problem in these applications is related to the control of turbulence inside the so called gray region where transition from RANS to LES takes place. The accuracy of the numerical scheme, as well as the grid resolution and the switching criteria all can influence the quality of the calculations. In particular, the rate of recovery of the unsteady turbulent fluctuations to the level of LES seems to be extremely sensitive to the aforementioned factors in developing flows in wakes or shear layers. In such cases, the loss of upstream turbulence in the transition from RANS to LES may lead to premature turbulence induction or delay separation thus deteriorating the quality of predictions. New criteria would be needed (see, e.g., Temmerman et al. [3]) to make the transition from RANS to LES smooth and controllable.

Another issue that needs further research and consideration and is also closely related to hybrid RANS/LES is the problem of prescribing unsteady boundary conditions at an inlet plane of LES domain in developing flows, for example, at the inlet of a swirling flow turbine combustor. Issues related to validation of such methodologies are addressed in the technical brief by de With et al.

The third paper by Balaras et al. is an example of new frontiers for applications of LES. The two papers by Krajnovic and Davidson illustrate the indispensable problems when LES is applied to a case that closely represents a complex engineering problem such as that of flow past a car model at high Reynolds numbers. These two papers constitute the most thorough study of this particular flow using LES with millions of grid nodes.

Also included in this issue are some DNS examples. While DNS is being expanded to new frontiers such as two-phase, non-Newtonian, reactive flows, the major problem remains not only the computer resources, but the questions and uncertainties related to theory. For example, the question of whether "DNS" of flow and heat transfer with only a reduced chemical reaction mechanism to simulate turbulent flames is a "true" DNS or not is a matter of debate. Nevertheless, the number of papers that are being published under the classification of "DNS" is also increasing rapidly. It used to be that the acronym DNS was more or less synonymous to an "exact" solution of the physical problem solved with extremely accurate numerical schemes. All relevant time and length scales were resolved so that experiments were not necessary to validate the simulations. Nowadays, nominally second-order schemes on non-structured grids are being used to perform "DNS." In such situations it becomes necessary to verify the so-called "DNS" as well, for example Orozco et al. [12]. The work by Meyers et al. [10], where they apply Richardson extrapolation to determine discretization errors in the predicted length scales of DNS of decaying homogenous isotropic turbulence is a good example of assessment of numerical errors in DNS which seem to appear more pronounced in secondary quantities that are derived by derivation from the primary mean quantities. It seems that this trend will continue and more and more DNS calculations will be performed, albeit with limited grid resolution to more complex flows such as gas turbine flows. The issue of when a DNS is actually DNS must be debated thoroughly.

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