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Guest Editorial

Computing Turbulent Flow Dynamics With Implicit Large Eddy Simulation

The Navier-Stokes equations (NSE) can be solved directly for laminar flows, but the wide range of eddy scales to be captured prohibits direct numerical simulation for the high Reynolds-number turbulent flows of technological interest. The prevalent remedy to this resolution problem has traditionally involved the Reynolds-averaged Navier-Stokes (RANS) approach, with averaging typically carried out over time or across an ensemble of equivalent flows. The applicability of RANS typically requires that time scales associated with organized unsteady motion be substantially larger than those of turbulent motion. Such statistically steady flow assumptions can be satisfied in many (e.g., low-frequency dominated) unsteady flow applications, but most turbulent flows of interest do not fall into this category.

A more viable approach is the large eddy simulation (LES) approach [1]. LES is based on the expectation that the physically meaningful scales of turbulence can be split into two groups: one consisting of the resolved geometry and regime specific scales, and the other associated with the unresolved smallest eddies in the flow, for which the presumably more-universal dynamics is represented with subgrid scale (SGS) closure models. Scale separation is achieved by solving the low-pass filtered NSE, and using explicit SGS models introduced for closure prior to discretization. In the absence of an accepted universal theory of turbulence to solve the problem of SGS modeling, the development and improvement of such models has been driven by pragmatic practice dependent on the rational use of empirical information. In addition to the physics based difficulties in developing and validating SGS models, one is faced with simulations where contributions from numerical truncation terms can be as significant as those from SGS models in typical LES strategies. LES resolution requirements can thus become prohibitively expensive for practical flows and regimes of interest. Implicit LES (ILES) effectively addresses the seemingly insurmountable issues posed to LES by under-resolution, by relying on the use of SGS modeling and filtering provided implicitly by physics-capturing numerics of a broad class of high-resolution, non-linear finite-volume methods.

Increasing interest in ILES techniques is reflected in recent dedicated sections in archival journals [2,3], dedicated chapters in CFD textbooks [4], and by the publication of the first comprehensive book synthesizing our current understanding of the theoretical basis and accomplishments of ILES [5]. Timely ILES issues were addressed in two very-well attended minisymposia on “Computing Turbulent Flow Dynamics with ILES” at the 2006 ECCOMAS CFD conference at Egmond aan Zee, Netherlands, September 5–8, 2006. Five papers selected from the invited sessions and two other separately invited papers were assembled in the present special issue of JFE to provide a broad state-of-the-art perspective.

The first four papers deal with fundamental studies using modified equation analysis and tests in basic cases for which good reference data are available. Grinstein and Fureby discuss a class of flux-limiting methods used for ILES in both, incompressible and compressible regimes, focusing on their commonalities and basic performance. Comparative verification tests of ILES and classical LES are used to address performance of the various strategies in predicting transition and turbulence decay. Mosedale and Drikakis present an assessment of very high-order ILES models for multi-component compressible flows using WENO methods with fifth- and ninth-order of accuracy. Rider addresses SGS modeling issues arising from the application of ILES in the simulation of compressible turbulent flows, focusing on the form of the effective SGS model for the conservation of mass equations. Thornber and Drikakis report on ILES studies of multi-component compressible turbulent mixing featuring complex flow physics such as Richtmyer-Meshkov instability and transition to turbulence, including detailed comparisons against shock-tube experiments.

The last three papers address issues in simulations of extremely complex flows of interest in engineering, threat reduction management, and geophysics, for which whole-domain scalable laboratory (or field) studies are typically impossible or very difficult. Deterministic simulation studies are very expensive and critically constrained by difficulties in modeling and validating all the relevant physical sub-processes, as well as in acquiring all the necessary and relevant boundary condition information. Fureby first discusses the application of ILES to a variety of complex engineering-type applications ranging from incompressible external flows around typical naval applications to external and internal supersonic flows in aerospace applications. Large scale urban simulations are then discussed by Patnaik et al. Airborne contaminant transport in cities presents challenging new requirements for computational fluid dynamics. Turbulence is one of the most important of these phenomena and yet the overall problem is sufficiently difficult that the turbulence must be included efficiently with an absolute minimum of extra memory and computing time. Finally, Smolarkiewicz et al. present studies of geophysics using the ILES methodology. The difficulties of modeling the dynamics of the global ocean and atmosphere are compounded by the broad range of significant length scales and by the relative smallness of the vertical height of these boundary layers in comparison to their horizontal extent, which accentuates the importance of the backscatter of energy to the larger scales of motion.

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