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# Book Reviews

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## *Implicit Large Eddy Simulation: Computing Turbulent Fluid Dynamics*

Edited by Fernando F. Grinstein, Len G. Margolin, and William J. Rider, Cambridge University Press, New York, 2007, 560 pp., 20 color plates, $120.00

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IMPLICIT large eddy simulation (ILES) is a relatively new approach to the numerical simulation of turbulent flows. The book consists of 18 chapters written by various authors who are experts in the development and use of ILES. However, far from merely being a collection of review papers, this is a well-coordinated text presenting a coherent view of this promising tool.

Most fluid flows of interest in engineering, geophysics, and astrophysics are turbulent, and the effects of the turbulence are of major importance. Computational fluid dynamics (CFD) has become a valuable tool in predicting and studying turbulent flows, complementing physical experimentation and theory. Large eddy simulation (LES) is a compromise between simulating all the relevant length scales in a turbulent flow using direct numerical simulation (DNS), which is computationally very expensive and infeasible for high Reynolds number flows, and modeling all of the turbulence by solving the Reynolds-averaged Navier–Stokes (RANS) equations for only the time-averaged (or ensemble-averaged) flow quantities. In LES, the large-scale turbulent motion is simulated using a computational grid that is coarser than what would be needed in a DNS, whereas the effect of the small-scale unresolved part of the flowfield is usually modeled with an explicit subgrid-scale (SGS) model. One issue with LES is that the simulation is not well resolved (because, by definition, the small scales are not captured). Therefore, numerical error can affect the smaller resolved scales and interfere with or even overwhelm the SGS model. With ILES, no SGS model is used; instead, the numerical dissipation associated with the computational scheme is used as an implicit SGS model. There is some justification for this because the main function of an SGS model is to provide the correct dissipation rate of turbulent kinetic energy, which is passed down to the small scales through the nonlinear cascade process. There is no single ILES method, but most of the formulations presented in this book are based on nonoscillatory finite volume (NFV) methods, which provide at least second-order accuracy in smooth regions but use nonlinear flux limiters to provide dissipation when needed to regularize the smallest resolved scales. The advantages of ILES are its simplicity and robustness.

The use of these nonlinear numerical methods to simulate turbulence is controversial within the LES community, because the schemes were originally developed for problems with shock waves and there is concern that they are too dissipative. However, the book points out that there is a strong connection, both historically and functionally, between shock-capturing schemes and SGS modeling. ILES has been used for a long time in the computational physics community for solving difficult problems involving turbulent flows with strong transient shock waves. The goal of this book is to advance the acceptance of ILES for the simulation of turbulent flows in more general contexts. Toward that end, the book provides a theoretical justification for the ILES approach and shows many successful examples of its use.

The book is divided into four sections. The first section provides the motivation and background for ILES. It starts with a chapter by Jay Boris in which he gives an interesting historical perspective of his monotone integrated large eddy simulation (MILES) approach and the flux-corrected transport numerical method, which is a monotone shock-capturing scheme. Boris gives some explanations as to why this approach would work and presents several examples of flows in which MILES has been used. He is forthright in presenting some of the concerns that have been expressed about MILES (and about ILES in general), such as that it may not be able to capture important Reynolds number effects. Most of the examples presented throughout the book are of isotropic turbulence or various free shear flows in which the small scales are not dynamically significant and Reynolds number effects are not important (once it is large enough). Notable exceptions are the examples of wall-bounded flows discussed next. In chapter 2, the editors Grinstein, Margolin, and Rider provide a broad overview of ILES. They also present a simplified modified equation analysis (MEA) that shows that the leading-order truncation error

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terms are similar in form to an explicit mixed SGS model, having both a scale-similarity part and a dissipative part.

The second section is entitled “Capturing Physics with Numerics,” and it starts with a short overview of the traditional LES approach by Pierre Sagaut. Chapter 4 gives details on several numerical methods used to perform ILES. Most of the numerical methods are presented in considerable detail, with helpful discussions about the motivation for their development, whereas others are presented in a condensed form with only sketchy remarks provided. However, in all cases, ample references are provided for readers seeking more information about a particular method. One of the main concerns about ILES has been the lack of theoretical justification for the method. In chapter 5, Margolin and Rider give details of a modified equation analysis that provides a connection between truncation error and SGS modeling. They explore what characteristics are necessary for a method to be useful in ILES. They show that not all NFV methods behave in the same way, and care is needed to choose a numerical method that provides the proper scaling of the truncation error. The authors also make it clear that there are limitations to the MEA analysis. Chapter 6 by Adams et al. gives an overview of the approximate deconvolution method (ADM), which is a structural SGS model in the context of traditional LES. An extension called the adaptive local deconvolution method (ALDM) is then presented, which fits within the ILES approach. I found the mathematical development of ADM and ALDM difficult to follow; however, the authors perform an interesting analysis of the implicit SGS dissipation rate in their simulation of transition in a Taylor–Green flow.

The third section of the book, “Verification and Validation,” showcases a wide range of problems solved using ILES. Because there are variations among ILES methodologies (just as there are with LES), each needs to be validated for the intended application. The type and thoroughness of validation analysis performed varies depending on the particular example. For instance, the simulations of compressible decaying isotropic turbulence at high turbulent Mach numbers can only be compared with themselves, as the grid resolution and Reynolds numbers are varied because the flow parameters are beyond the capability of DNS and there are no experimental data under these conditions. Other cases, such as noncircular jets, are evaluated using qualitative comparison with flow visualizations from experiments, showing that the relevant vortex dynamics are captured, and only limited quantitative comparisons are included. For other cases, detailed experimental data are available and comparisons with mean and turbulence statistics are made. However, some of the comparisons only include integrated quantities, such as lift or drag coefficients, which are important for engineering analysis but may not be sensitive measures of the performance of the simulations. From the perspective of the broader LES community, the most useful comparisons include experimental data, ILES, traditional LES, and RANS results. There are a limited number of examples in which all of these are included.

One of the greatest concerns about ILES is its ability to work for wall-bounded flows, because turbulent boundary layers are dependent on the small-scale dynamics occurring in the viscous near-wall region. This is a difficulty for traditional LES as well. Because the viscous sublayer becomes extremely thin as the Reynolds number increases, whereas the outer boundary-layer scales as a weak function of Reynolds number, LES of wall-bounded flows often uses wall models so that only the turbulence away from the wall needs to be simulated. This approach is taken by Fureby et al. in their application of ILES to incompressible wall-bounded flows. They show good results, starting with a simple channel flow and cylinder wake, progressing to flow over a cube mounted on a wall, and, finally, to flow over a ship hull. Fureby et al. apply ILES to compressible wall-bounded flows, including a flat-plate boundary layer, shock/boundary-layer interactions in compression corners, and a base flow for a supersonic projectile. In these cases, wall models are not used; the ILES is applied with a grid fine enough to resolve the near-wall region. However, the ILES is run at Reynolds numbers lower than those of the experiments, which leads to mixed results when making comparisons. Steinhoff et al. also simulate flows with solid walls, but they mostly look at the effect of wakes computed with the vorticity confinement method.

The last section gives examples of grand challenge problems amenable to ILES. These include examples of geophysical and astrophysical flows at extremely large Reynolds numbers, engineering flows of large or complex systems, and dispersion of a contaminant in a realistic urban environment. In some cases, other physical processes need to be modeled in addition to the fluid mechanics. For example, one difficulty with the urban environment problem is acquiring sufficient resolution of features of the landscape that impact the dispersion of the contaminant, while still allowing the calculation to be efficient enough to include all the relevant physics.

The book concludes with a summary of the ILES method and a discussion of open research issues. Many of the outstanding issues for ILES are the same as for traditional LES, such as the generation of appropriate boundary conditions. Others are specific to ILES, such as extension of the modified equation analysis. Both ILES and traditional LES require further validation. As the editors note, “the further development and acceptance of the ILES methodology depends on the continued success of researchers in applying this approach to complex problems of academic and practical interest.”

There are two minor annoyances about the printing of the book that I feel I need to point out. For the most part, the quality of the figures are excellent, especially the color plates; however, a few of the figures are quite fuzzy. Also, in chapters 10–13, certain symbols are not printed, leaving blank spaces, which would force one to search the cited references if that information were needed.

*Implicit Large Eddy Simulation: Computing Turbulent Fluid Dynamics*, edited by Grinstein, Margolin and Rider, is a timely addition to the references on turbulence simulation and modeling. It provides a significant step forward within the large eddy simulation community in the discussion concerning ILES. I recommend the book highly to researchers in the field, to graduate students (so they can see an alternate approach to that of the traditional LES methodology), and to CFD practitioners who are starting to use hybrid RANS/LES methods to solve complex turbulent flow problems.

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