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Book Reviews

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Large Eddy Simulation for Incompressible Flows, 2nd Edition

Pierre Sagaut, Springer-Verlag, New York, 2003, Corrected 2nd Printing 2004, 426 pp., $77.95

This new edition of Pierre Sagaut 's *Large Eddy Simulation* (LES) book is timely and extremely welcome in the fluid dynamics community. Compared to the first edition that appeared two years earlier, the original material has been significantly expanded and new chapters have been included to increase coverage of this fast-growing and challenging field of turbulent flow simulations.

Turbulent flows are of considerable importance in many applications in aerospace engineering, geophysics, and astrophysics. High-Reynolds-number turbulent flows involve a broad range of length- and timescales. The largest scales are related to the specific geometry, boundary conditions, and regime considered, and the smallest are associated with the dissipation of turbulent energy through viscosity. Given the fact that numerical simulations involve discretization of the flow conservation equations on computational grids having finite resolution and dimensions, critical LES issues to be addressed relate to the appropriate modeling of the unresolved flow features (subgrid modeling) and of the required open and wall boundary conditions (supergrid modeling).

Relevant aspects of model approximation levels and scale separation are addressed by Sagaut in Chapter 1. Capturing the dynamics of all relevant scales of motion, based on the numerical solution of the Navier–Stokes equations, constitutes direct numerical simulation (DNS); this is prohibitively expensive in the foreseeable future for most practical flows of interest at moderate-to-high Reynolds number. On the other end of computer simulation possibilities, the Reynolds averaged Navier–Stokes (RANS) equations, with averaging typically carried out over time, over homogeneous directions, or across an ensemble of equivalent flows, have been employed for turbulent flows of industrial complexity. LES has become the effective intermediate approach between DNS and RANS, capable of simulating flow features that cannot be handled with RANS, such as significant flow unsteadiness and strong vortex-acoustic couplings, and providing higher accuracy than RANS at reasonable cost.

The main assumptions of LES are as follows: 1) transport is largely governed by large-scale unsteady features, and such dominant features of the flow can be resolved in space and time; and 2) the ideally less-demanding (i.e., universal and large-scale independent) accounting of the unresolved smaller-scale flow features can be undertaken by using suitable sub-grid-scale (SGS) models. In this context, a good discussion of the mathematical formulations of scale separation and closure issues is given in Chapters 2 and 3, respectively, and the various attempted strategies for the problem of SGS modeling are introduced. It is crucial to note here that, in the absence of an accepted universal theory of turbulence, the development and improvement of SGS models are unavoidably pragmatic and based on the rational use of empirical information. Moreover, a universal definition of LES is also not well established. Thus, it is very important for the reader hoping to learn about the “best” LES modeling approach to have the conventional wisdom of what is traditionally postulated and/or assumed stated upfront in unbiased form, and Sagaut manages to do this in a very attractive and consistent fashion.

The classical SGS models are extensively covered in Chapters 4–6, and some discussion of the nonclassical approaches is now also included. The *functional* SGS model proposals, where the action of the SGS stress τ on the filtered velocity is modeled (rather than modeling τ itself) to represent kinetic energy transfers, are presented in their isotropic (Chapter 4) and anisotropic (Chapter 5) versions. Both the forward and backscatter cascade modeling problems are very well addressed in this context. Within the section of forward cascade modeling (Chapter 4), Sagaut also reports on alternative (nonclassical) implicit SGS modeling efforts, employing the unfiltered flow equations instead of the filtered ones. Several nonconventional approaches are discussed, namely the monotone integrated LES (MILES), adaptive flux reconstruction, and variational schemes with embedded subgrid stabilization. The major focus of these new approaches has been on the inviscid inertial-range dynamics and regularization of the underresolved flow, based on ab initio scale separation with additional assumptions for stabilization or applying monotonicity via nonlinear limiters that implicitly act as a filtering mechanism for the small scales (the underlying concept supporting MILES). Interestingly enough, the latter concept actually goes back to the 1950s to von Neumann and Richtmyer, who used artificial dissipation to stabilize finite difference simulations of flows involving shocks. As a matter of fact, this artificial dissipation concept also motivated Smagorinsky in developing his scalar eddy-viscosity concept based on the principles of similarity in the inertial range of three-dimensional isotropic turbulence, and not only do the LES and shock capturing approaches share a common start but they have also evolved in very similar ways.

The more sophisticated *structural* models (focusing on modeling τ) are discussed in Chapter 6. The presentation includes models based on the scalar similarity hypothesis, approximate deconvolution approaches based on using series expansion approximations to the formal inverse-filtering operation, implicit structural approaches, and mixed models that in essence combine dissipative functional models with the more accurate but typically unstable structural formulations. The results from such mixed models have been mostly satisfactory, but the implementation and computational complexity of these improved combined approaches have limited their popularity.

Sagaut discusses the important issues of dynamic interpretation of LES, competition between numerical errors and actual (explicit) SGS modeling and filtering, and provides some remarks on the use of artificial dissipations in Chapter 7. Closely related aspects of analysis and validation of LES data are examined in Chapter 8. Because of the need to distinctly separate (i.e., resolve) the effects of explicit filtering and SGS reconstruction models from those due to discretization, carrying out *well-resolved* (i.e., grid-independent) LES can typically amount in practice to performing a coarse DNS. These practical difficulties have motivated some of the nonclassical approaches discussed earlier (e.g., MILES) and coupling of LES with multiresolution/multidomain techniques (surveyed in Chapter 10), as well as new trends combining RANS with LES, to exploit the best features of both approaches in a complementary manner in so-called hybrid RANS/LES (discussed in Chapter 11), which might be unavoidable in the foreseeable future for realistic whole-domain complex configurations.

Although SGS modeling issues have motivated intense research in the past 30 years, comparatively less attention has been devoted to the equally relevant supergrid modeling aspects, and their importance is often overlooked. Because actual boundary condition choices *select* flow solutions, emulating particular flow realizations demands precise characterization of their initial conditions (e.g., inflow) and other relevant conditions (e.g., of asymptotic flow or at solid and facility boundaries). This flow characterization issue is a challenging one when laboratory realizations are involved and LES model validation is attempted because the reported laboratory information is typically insufficient and/or inadequate. Achieving closure of the supergrid model based on laboratory data requires identifying appropriate data acquisition and its suitable postprocessing for use in LES. Chapter 9 presents a very thorough presentation of supergrid modeling issues relevant to LES, with particularly good special focus on those for modeling turbulent inflow and wall boundary conditions.

Finally, practical implementation issues are discussed in Chapter 12. Chapter 13 is devoted to a discussion of very representative examples of applications. Useful appendices on "Statistical and Spectral Analysis of Turbulence" and on "EDQNM Modeling" help ensure the self-contained nature of the volume. The survey of the relevant literature is fairly extensive and includes nearly 550 references.

Other than review papers and conference proceedings, Pierre Sagaut 's book on *Large Eddy Simulation for Incompressible Flows* is still the only available reference presenting a systematic organized discussion of the state of the art of LES. I very highly recommend it as of fundamental interest to graduate students and basic research scientists, as well as professionals involved in the design and analysis of complex turbulent flows.

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