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Book Reviews

Hydrodynamic and Magnetohydrodynamic Turbulent Flows: Modelling and Statistical Theory

Akira Yoshizawa, Kluwer Academic Publishers, Dordrecht, The Netherlands, 1998, 410 pp., $175.00

This book presents a statistical approach to turbulence theory, with particular stress on compressible and magnetohydrodynamic flows. The book is in the series Fluid Mechanics and Its Applications published by Kluwer.

The first two chapters are devoted to introductory remarks and the derivation of the governing equations. In Chapter 3 small-scale turbulence is discussed, the Fourier decomposition is introduced, and the velocity and passive-scalar spectra and their properties are discussed. This is followed by a section on homogeneous isotropic turbulence theory, mostly centered on the direct interaction approximation (DIA) approach.

Chapter 4 is dedicated to conventional turbulence modeling, with an interesting discussion of the properties and limitations of the κ–ε approach and sections on nonlinear and second-order models. The modeling of passive scalars is also discussed. The next chapter concentrates on large-eddy simulations (LES) and introduces the formalism. A fairly complete panorama of state-of-the-art subgrid-scale (SGS) models follows, including some very recent developments.

Chapter 6 discusses the two-scale direct interaction approximation (TSDIA), a theory developed by the author himself to overcome the shortcomings of the DIA approach. The chapter is extensive, and the mathematical development of the theory is exposed quite clearly. Results of the theory are related to eddy-viscosity and Reynolds stress models, and implications for the parameterization of the SGS stresses are presented. Combination of this method with the Markovianization procedure results in the Markovianized two-scale (MTS) approach, which is discussed in Chapter 7.

In Chapter 8, compressible flow is discussed and the author extends the TSDIA and MTS approaches to the compressible case. Although the theoretical development is performed on the basis of the ensemble-averaged quantities, the author tries to relate the theoretical results to the modeling required in the (more commonly used) mass-weighted equations of motion. Chapters 9 and 10 are dedicated to magnetohydrodynamic flows. This is an area in which the author has published significant contributions to the archival literature.

The book is sufficiently clearly written, and I found the mathematical exposition to be understandable. However, I doubt that readers with only an undergraduate knowledge of fluid dynamics (which the author states as the only prerequisite in his introductory remarks) would find the material approachable. It is perhaps better suited to a more advanced audience with a stronger mathematical background than the typical undergraduate.

The book concentrates on the author's own research. With the exception of the chapter on LES, in which a fairly complete overview is presented, the discussion of statistical theories is fairly minimal. This feature, in this reviewer's opinion, helps focus the book but at the same time decreases its value as a reference on turbulence and its modeling.

The purely statistical approach that the author uses also has some limitations, especially because it is not accompanied by many quantitative illustrations of the behaviors described in mathematical terms. A case in point is Chapter 4, on conventional turbulence modeling. The chapter contains some useful discussions, for example, that of the asymptotic behavior of the κ and ε equations in wall-bounded flows. However, a plot of the budget of κ is missing. Such a figure could help in understanding some of the points raised by the author and also give the readers, especially the less advanced ones, a better understanding of the physical mechanisms (diffusion, dissipation, production) at play. The lack of quantitative graphical illustrations of the points raised and discussed is, in this reviewer's opinion, a shortcoming: first because of their value to enhance and facilitate the understanding of rather difficult material and second because this lack prevents the reader from being able to evaluate the relative importance of the various assumptions (and shortfalls) of a model. Similar considerations apply throughout the book.

Though not an expert in the field, I found the two concluding chapters on magnetohydrodynamic flows quite interesting. They, however, were also characterized by a limited number of quantitative comparisons or predictions, as described earlier.

In summary, I consider this book a valuable introduction to a class of statistical turbulence theories. It is also an interesting discussion of magnetohydrodynamic turbulence. As such, it has a place on the shelves of advanced researchers in the field. On the other hand, readers who expect to find a reference book on turbulence modeling might be disappointed.

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Intermediate Finite Element Method, Fluid Flow and Heat Transfer Applications

Juan C. Heinrich and Darrell W. Pepper, Taylor & Francis, Inc., Bristol, PA, 1999, 596 pp., $79.95

The authors have produced a very readable textbook covering a broad range of topics. There is a wealth of examples illustrating many subjects in fluid mechanics and heat transfer and associated literature references for more in-depth study. The book is a worthwhile addition to the library of students and practitioners of the finite element method.

The subject matter is ambitious and comprehensive, addressing such complex applications as free surfaces; buoyancy and stratification; and unsteady, viscous flows. Additional examples are used to illustrate the application of the finite element method to turbulence and to high-speed chemically reacting flow. The stated objective of the book is to address fluid flow and heat transfer, with emphasis on the physical aspects of the problem and how they relate to the mathematical aspects. The authors cover this territory well and succeed in making the important distinction between convergence and accuracy and relevance to solving practical problems. Emphasis is also placed on obtaining a solution within the confines of time and computer limitations, without getting lost in the minutiae of converging to machine zero. Readers are reminded several times that obtaining any solution is predicated on the user's understanding of the underlying physics. Because the finite element formulation focuses on a single element, there is no intrinsic predisposition toward a structured or unstructured approach, and both are covered. In fact, the current activity in unstructured finite volume methods makes much recourse to the extant finite element literature.

Twelve chapters plus an appendix constitute the book. Chapter 1 presents an historical review of the finite element method, identifying the origin of current developments in the seminal work of Courant in 1943. A statement of the governing equations and boundary conditions is contained in Chapter 2. Chapters 3–7 discuss the finite element method and related numerical issues, with heat conduction as the vehicle. Triangular and rectangular elements are introduced with the Galerkin method, along with higher-order and isoparametric elements, quadrature and reduced integration, nonlinearity, time dependence, and mass lumping. Chapters 8–10 cover physical phenomena, including steady convection and unsteady convection–diffusion and concluding with incompressible, viscous flow. The Petrov–Galerkin method is derived, phase and dissipation errors are discussed, and the penalty function formulation is developed. A mixed formulation and satisfaction of the LBB condition are then presented. Chapter 11 contains an overview of structured and unstructured mesh generation, Delaunay triangulation, node renumbering and minimum bandwidth, and adaptive methods (r-, h-, and p-type). Chapter 12 concludes the book with further examples from the open literature.

Clearly a single textbook cannot cover every aspect of computational fluid dynamics, even within the limited purview of the finite element method. Yet with emphasis placed on practical applications rather than theory, a reader expects to see turbulent flows dealt with in depth because few industrial problems are two dimensional, laminar, and incompressible. Turbulence model equations are introduced, but there is no further elaboration. In addition, though many examples are provided, precious few results are compared with measurements or exact solutions, leaving the reader with, at best, a qualitative appreciation for the accuracy. Finally, aerodynamic flows in general are not represented. The Euler equations are not addressed, nor are upwind differencing and the large body of literature concerning shock capturing, monotone methods, the total variation diminishing property, and the entropy principle.

Any successful textbook must distinguish itself from the plethora of others, but it must avoid isolating itself from the few existing standards, in the sense of terminology and useage. In this regard, the book has some surprising omissions and confusing terms. The heart of a finite element solver is the numerical linear algebra, yet the authors barely touch on the issue. Where it is mentioned, a somewhat confusing terminology is introduced, that of a "direct iteration method," in contrast to the more conventional segregation of methods into direct and iterative classes. In dealing with nonlinear equations, the Newton Jacobian is termed the "tangent operator." In the fully discrete equations, the part that converges to zero at steady state is termed the "out-of-balance" vector, instead of the more common "residual." Oscillatory pressure fields resulting from the penalty method are deemed viable, merely requiring averaging to smooth the wiggles—a potentially dangerous prospect for the inexperienced. In choosing a time step for unsteady calculations, more importance appears to be relegated to convergence and stability, with less attention paid to the demands of accuracy from the intrinsic unsteadiness.

Grid generation is well developed and has become essentially an industry in itself, and in Chapter 11 a substantial number of pages is devoted to its description. Yet the reader is not provided with any guidelines for what constitutes a good grid. For example, work published in 1971 by Roberts on distribution functions for boundary layers demonstrates that tanh, for the grid normal to a wall, is compatible with the functional variation of the velocity distribution. The authors offer no rules of thumb with regard to the number of points required to resolve viscous layers or the number of points that should be placed between the temperature peak and the wall in a nonunity Prandtl number flow for accurate heat flux calculations. With respect to unstructured grids, finite volume users have found that wall boundary layers are poorly resolved, and they have resorted to hybrid grids, with a structured layer at the wall and unstructured elsewhere, as finite element methods immune from this inaccuracy. The authors caution that experience is necessary for generating good grids but do not incorporate their valuable experience.

In summary, the book can be a bit confusing, and for the industrial user, the absence of information on turbulent flow calculations will necessitate recourse to other sources. That said, the book contains much useful information on the derivation and application of the finite element method in fluid mechanics and heat transfer.

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