AIAA JOURNAL
Vol. 39, No. 9, September 2001

Book Reviews

Perspectives in Fluid Dynamics

Edited by G. K. Batchelor, H. K. Moffatt, and M. G. Worster, Cambridge University Press, New York, 2000, 631 pp., $160.00

Cambridge played a major role in fluid mechanics beginning shortly after the Second World War. This was almost entirely attributable to George Batchelor and the Department of Applied Mathematics and Theoretical Physics that he put together and the *Journal of Fluid Mechanics* (*JFM*) that he founded, which became the journal of record in fluid mechanics.

The present book was George's inspiration. According to the preface, he evidently thought of it as a sequel to his textbook *An Introduction to Fluid Dynamics*, giving the reader a taste of the great breadth that the subject had attained after 30 years. He played a full part in choosing the authors and defining the style of the book, but his health declined rapidly, and he died before the project could be completed. Of course, the editors say that "...the coverage of fluid-dynamical research is in no way exhaustive,...." However, having positioned the book as in some sense a sequel to *An Introduction to Fluid Dynamics*, there is an implication that these are the important areas of fluid dynamics, or at least that they exemplify the interesting current research areas.

The areas covered are Interfacial Fluid Dynamics (Davis); Viscous Fingering as an Archetype for Growth Patterns (Couder); Blood Flow in Arteries and Veins (Pedley); Open Shear Flow Instabilities (Huerre); Turbulence (Jimenez); Convection in the Environment (Linden); Reflections on Magnetohydrodynamics (Moffatt); Solidification of Fluids (Worster); Geological Fluid Mechanics (Huppert); the Dynamic Ocean (Garrett); and Global-Scale Atmospheric Circulations (McIntyre).

I hasten to say that the authors are exceptionally distinguished people and the papers are all well written and interesting. Of the 11 authors, 5 are from Cambridge and 3 more have strong Cambridge affiliations, which tends to suggest that the editors thought that the best people usually are connected to Cambridge somehow. The three with Cambridge associations are Paul Linden, now resident at La Jolla; Steve Davis of Northwestern, the new editor of *JFM*; and Chris Garrett of Victoria, British Columbia, a former student of Bretherton at Cambridge. Linden and Davis were the only U.S. contributors. The remainder are two Frenchmen and a Spaniard.

It is inevitable that this book be compared to the *Annual Review of Fluid Mechanics* (*ARFM*), which tries over the course of several years to cover what its editorial board thinks are the interesting areas of fluid mechanics. There is overlap here because Linden is a member of the Editorial Board of *ARFM* and Davis is an Associate Editor. (By way of full disclosure, I should admit to being editor of *ARFM*.) In addition, this book should probably be compared to *Research Trends in Fluid Dynamics* (*RTFD*), edited by Lumley, Acrivos, Leal, and Leibovich, AIP Press, Woodbury, N. Y., 1996.

The authors of the chapters in *RTFD* are equally distinguished, and there is considerable overlap in the list of topics covered in that book and in the present book. The only ones in the present volume not covered in *RTFD* are growth patterns, solidification, and geological fluid mechanics, all important areas. On the other hand, some 14 areas are covered in *RTFD* that are not covered in the present volume, notably the application of dynamical systems theory to fluid mechanics, granular materials, acoustics, combustion, direct numerical simulation and large eddy simulation, rarified gas dynamics, multiphase flows, and control, equally important areas. It is only fair to admit that the aim in the present book was for somewhat longer papers than those in *RTFD*, so that fewer topics could be included.

The comparison with *ARFM* is very similar, because *ARFM* publishes some 20 papers a year, and the topics over the course of several years cover approximately the same area as those of *RTFD*. The authors appearing in *ARFM* are often (though not always) a bit younger and slightly less well known than their counterparts in the present volume.

So, what is the bottom line? This is a collection of very interesting papers by distinguished authors. The choice of authors might be regarded as perhaps a bit parochial. The choice of subjects certainly leaves out many important areas. I do not think the book can be regarded as in any sense a sequel to Batchelor's *An Introduction to Fluid Dynamics*. The preface suggests that the book "...could be used as an accompaniment to a graduate-level course in fluid dynamics." That is true, but I think that, unless supplemented by other material, it would give a rather one-sided view of current research.

John L. Lumley
Cornell University

Statistical Theory and Modeling for Turbulent Flows

P. A. Durbin and B. A. Pettersson Reif, Wiley, New York, 2001, 285 pp., $115.00

This book seeks to provide the reader with a comprehensive introduction to statistical turbulence theory and modeling. The material is conveniently organized in three major parts to facilitate the use of the book as a text for both introductory and more advanced graduate-level courses. Part I (Chapters 1–5) provides an overall background on turbulence phenomenology and the theory of Reynolds averaging. Part II (Chapters 6–8) focuses on single-point turbulence models for the Reynolds-averaged Navier–Stokes equations (RANS). Part III (Chapters 9–11) provides more advanced readers with an overview of the theory of homogeneous turbulence. As stated in the Preface, the objective of the book is to provide those working in the area of computational fluid dynamics for turbulent flows with sufficient background to understand the origin of various turbulence models and the knowledge to make educated decisions when called upon to select a closure model for a particular application. The potential reader should be made aware, however, that the word *Modeling* in the title of the book refers exclusively to statistical Reynolds-averaged models. Turbulence models for the large-eddy simulation approach are not covered.

Chapter 1 (Introduction) presents a general overview of the problem of turbulence and discusses the concept of a turbulent eddy, the energy cascade, viscous dissipation, and instantaneous vs time-averaged descriptions of turbulent flows. The conceptual difficulties arising from the nonlinearity of the Navier–Stokes equations and the need for closure of time-averaged models are illustrated very effectively using a simple example of a nonlinear random process. The chapter closes with a brief overview of categories of turbulent flows.

Chapter 2 (Mathematical and Statistical Background) starts with a thorough discussion of dimensional arguments of the scales of turbulence leading to the derivation of Kolmogorov's $-\frac{5}{3}$ law, followed by an overview of the basic tools of statistical analysis. A very elegant presentation of Taylor's dispersion theory is presented, and the concept of eddy-diffusivity is introduced and linked to Lagrangian concepts of turbulent mixing. The chapter concludes with an extensive and thorough review of Cartesian tensors and a brief treatment of non-Cartesian tensors and curvilinear coordinates.

The RANS, along with the transport equations for the Reynolds stresses, the turbulence kinetic energy, and the turbulent flux of a passive scalar, are derived in Chapter 3. Physical interpretation of the various terms in the Reynolds-stress transport (RST) equations is given in terms of the mixing length concept and budgets of various terms from direct numerical simulations.

Chapter 4 (Parallel and Self-Similar Shear Flows) briefly reviews the fundamental physics of several building-block turbulent flows. Inner-variable scaling, the law of the wall, and issues related to roughness modeling are introduced in the context of plane channel flow, along with a short discussion of turbulent boundary layers. Free shear flows (jets, mixing layers, and wakes) are then discussed, with emphasis on the concept of self-similarity. The last part of this chapter discusses heat and mass transfer in parallel flows and boundary layers and Taylor's mechanism of streamwise shear dispersion.

The concept of coherent structures is introduced in Chapter 5 (Vorticity and Vortical Structures). The discussion in this chapter is brief and largely qualitative, but it succinctly summarizes the state of knowledge on this important topic. Examples of coherent structures are presented for shear layers, massively separated wakes, and wall boundary layers. The distribution of vorticity at the various scales of motion, the relation between vorticity at small scales and energy dissipation, and the mechanism of vortex stretching are also covered.

Chapter 6 (Models with Scalar Variables) is the first chapter of the second part of the book and begins the discussion on turbulence modeling for the RANS equations by focusing on models using scalar variables. In this as well as in subsequent chapters on modeling, the authors have attempted to explain how the various models were developed and identify where rigorous mathematics ends and empiricism enters the model derivation process. The material is presented according to the chronological evolution of turbulence models. Integral boundary-layer methods are discussed, followed by algebraic, mixing-length-type models. Subsequently the k–ε model is derived, and the process by which the various model constants are calibrated is explained. Various approaches for handling the near-wall region are discussed, including wall functions, low-Reynolds-number modeling, and the two-layer approach. The standard k–ω model and its recent shear-stress transport variant are then presented. The so-called stagnation-point anomaly and various remedies for mitigating it, along with approaches for modeling transition to turbulence, are also briefly discussed. The chapter ends with the presentation of the Spalart–Allmaras eddy-viscosity transport model.

Models with tensor variables are discussed in Chapter 7. The chapter starts by discussing the limitations of isotropic, eddy-viscosity models and establishing the need for developing second-moment closures. The modeling of the pressure redistribution tensor is discussed in detail by adopting the standard decomposition of this term into slow and rapid parts. Analytic solutions of the modeled RST equations are presented for homogeneous shear flows, followed by a discussion of the physics of such models in curved shear flows. The discussion then shifts to the modeling of nonhomogeneous effects, including the treatment of the triple-correlation tensor, and various approaches for accounting for the effects of walls on the structure of turbulence, near-wall modeling, wall echo terms, and elliptic relaxation models being among the topics covered here. This section ends with the presentation of the V2F turbulence model, but the rationale for including this model in a chapter on models with tensor variables is not entirely clear. Even though the derivation of the model appears to have been inspired by elliptic relaxation ideas used in RST models, it does not actually involve any tensor variables (as explained on p. 180) and in essence is an isotropic, eddy-viscosity model such as those presented in Chapter 6. The last part of Chapter 7 is dedicated to Reynolds-averaged computations. This part begins with a very brief and simplified discussion on numerical issues, followed by several examples from applications of Reynolds-averaged models. However, the selection of the specific test cases is somewhat puzzling. Of all the many examples available in the literature, where a variety of isotropic and advanced turbulence models have been applied to complex three-dimensional flows of engineering relevance, the authors chose to focus on a few building-block, two-dimensional-in-the-mean flows (backward-facing step, flow around a triangle in a channel, etc.). Most of these cases have been calculated by the authors and their collaborators using the V2F turbulence model. Although they serve to illustrate the predictive capabilities of their V2F model (at least for the few two-dimensional cases considered), these test cases are by no means representative of the progress made in the field over the past decade.

A number of advanced topics are presented in Chapter 8. The concepts of Galilean invariance and realizability of RST models are first presented, followed by an extensive discussion of equilibrium solutions of the RST equations and the mathematical framework for deriving algebraic, nonlinear eddy-viscosity models. The last part of this chapter is devoted to second-moment modeling of passive scalar flux transport, buoyancy effects, and stratified shear flows.

The third and last part of the book (Chapters 9–11) deals with the theory of homogeneous turbulence. Chapter 9 (Mathematical Representations) introduces the fundamentals of the Fourier transform and the energy spectrum for homogeneous turbulence. Chapter 10 develops the Navier–Stokes equations in spectral space, and Chapter 11 presents the basic ideas of rapid distortion theory.

In summary, this is a timely and well-written book that I recommend to anyone interested in an in-depth, behind-the-scenes look into the development of engineering turbulence models. It can serve as the basis for developing both introductory and advanced-level graduate courses, a function that is greatly facilitated by the several problems at the end of every chapter. The authors should be commended for striking a good balance between the rigor of advanced mathematical tools and concepts and the complex-flow physics these tools and concepts are meant to explain and model. My only criticism of the book stems from the fact that in several places (and especially in Chapter 7) the authors have displayed very strongly their own modeling biases and in doing so they have diminished the value of an otherwise very valuable contribution. This caveat notwithstanding, however, I consider this book to be the best text available today on the subject of statistical turbulence modeling.

Fotis Sotiropoulos
Georgia Institute of Technology

Extended Surface Heat Transfer

A. D. Kraus, A. Aziz, and J. Welty, Wiley, New York, 2001, 1105 pp., $175.00

This book reviews the literature that pertains to heat transfer aspects of fins, also known as either extended or sculptured surfaces. In 1105 pages, nearly 800 references (the latest in 1995) are cited in the course of a useful exposition that is logically divided into 20 chapters and 2 appendices. The pattern of most of the chapters is of a literature survey first, followed by a derivation of describing equations and a recounting of results, and culminating in numerical examples that effectively illustrate the application of the information.

After the history of the topic is related in the introductory Chapter 1, the basics for an isolated fin are given, first along the lines presented in most undergraduate heat transfer textbooks and then extended. In Chapter 2, the mathematical treatment for nonconstant heat transfer coefficients is summarized. Optimal shapes of isolated fins are covered in Chapter 3, taking into account such practical factors as the true surface area of a tapered fin, the nonconstant heat transfer coefficient, and temperature-dependent thermal conductivity of the fin. Chapter 4 is basically a review of a first, undergraduate, course in heat transfer, presumably as an aid to readers in understanding predictions of heat transfer coefficients in forced and natural convection situations in later discussions. The utility of linear transformations, without attribution to techniques for analysis of electrical circuits, is laid out in Chapters 5 and 6 as a prelude for the algorithms for finned arrays and their optimization in Chapters 7 and 8. Chapter 8 is devoted to ducts with internal fins, and heat exchangers are the subject of Chapters 10–12. Fins with only radiative heat transfer, understandably motivated by applications outside a planetary atmosphere, are discussed in Chapter 13, and those with combined radiation and convective heat exchange are discussed in Chapter 14; combined radiation and natural convection is not covered, however. Effects of multidimensional heat conduction in the interior of a fin and the surface to which it is affixed are covered in Chapter 15. Unsteady conditions are emphasized in Chapters 16 and 17. Fins for boiling and condensing situations are the subject of Chapters 18 and 19, and such miscellaneous applications as heat pipes, solar collectors, and freezing and melting situations are wrapped up in Chapter 20.

The citations are distributed by decade as follows: 1990s, 10%; 1980s, 36%; 1970s, 27%; 1960s, 17%; 1950s, 5%; and earlier, 5%. Although most conditions that can be encountered are covered by at least one reference, comparisons of mathematical predictions with measurements are scanty. Also, there is little citation of the applications of computational fluid dynamic methods to the conjugate problem that would make most assumptions, especially regarding convective heat transfer coefficients, unnecessary.

This survey is likely to be of interest to all heat transfer academics and to heat transfer practitioners, such as those who work on electronics packaging problems and those who work to ameliorate limitations on heat transfer rates from surfaces.

Louis C. Burmeister
University of Kansas