AIAA JOURNAL
Vol. 38, No. 2, February 2000

Book Reviews

Turbulent Flows—Models and Physics

Jean Piquet, Springer–Verlag, New York, 1999, 761 pp., $199.00

Piquet declared that his aim was to provide a "most detailed presentation of the field of turbulence physics and modeling." He has certainly achieved this. There are 392 figures, 57 pages of references, and a 14-page list of symbols. The organization of the material is admirable, with helpful touches such as a list of subsections at the beginning of each main section and indications, in the list of symbols, of the page on which each is first used. The index is a surprising exception: the entries could have been subdivided more, to avoid having a list of 50 page numbers under "Dissipation" with no indication of which refer to the physics, which to the mathematical expression, which to the exact transport equation, and which to modeling. (This is not even the worst example!) One suspects it was generated automatically—indexing is an art.

The general approach is in the tradition of French mathematical physics, but the physics is not obscured by the mathematics; in fact, the mathematical undergrowth is at its densest in the descriptions of the more advanced turbulence models in Chapter 4, and this is no fault of the author's. Piquet's English style is good, and it is only occasionally that one is reminded that he is not writing in his native language. His meaning is always clear, and there are very few misprints. The book was printed from the author's camera-ready copy: this now-common evasion of the publisher's traditional duties of editing and composition does not seem to have had a beneficial effect on book or journal prices.

Chapter 1: The equations of motion. This is a short, fairly stiff but very rewarding mathematical chapter, drawing together the various properties of the Navier–Stokes equations, which are customarily distributed over a number of equations and formulas that, at first sight, look independent. The reader will need to store vector notation in half of the brain and tensor notation in the other because the author simply uses the notation that is more convenient at the moment.

Chapter 2: Principles of turbulence modeling. This covers Reynolds (most commonly time) averaging and the Reynolds-averaged Navier–Stokes (RANS) equations. The next section is on the "closure problem," which Piquet nicely describes (actually at the start of the section on eddy viscosity) as "tribute to pay to the convective nonlinearity of the Navier–Stokes equation and to the loss of information through the averaging procedure." The effect is that new unknowns (e.g., the Reynolds stresses) appear in the equations. The topic is discussed from a fundamental viewpoint: actually the section title, "The closure problem," is a little misleading because the section includes some peripheral matters such as frame indifference, which might have been better in an appendix to the chapter. The section on homogeneous and inhomogeneous flows also covers a wide range of topics, some of which are introductory to the next chapter, and is written around a description of isotropic turbulence and return to isotropy. In the next section, the author considers only the case of scalar eddy viscosity (and systematically exposes the errors and paradoxes that it produces). In fact, eddy viscosity can be defined more generally as the ratio of a Reynolds stress to the mean rate of strain in the same plane, which makes it a second-order tensor whose elements can be measured. One- and two-equation eddy-viscosity models for the Reynolds stresses are discussed here.

Chapter 3: Two-point homogeneous turbulence. Here "two point" is just an indication that the chapter deals mainly with (Reynolds-averaged) correlations between velocity fluctuations at two (or more) points in space and their Fourier transforms, which are the wave-number spectra. This is the lowest level of analysis at which one can deal with the central property of turbulence, its wide range of length scales. Here the essential closure problem is the modeling of the rate of transfer of turbulent kinetic energy (strictly, of each Reynolds stress) from one range of eddy sizes to another, usually from large to small. In the late 1940s there were many attempts to model the transfer rate, but none was satisfactory and only one or two people have since devised worthwhile models. Piquet—rightly, I think—puts his money on EDQNM. (I will not expand the acronym to full, jawbreaking length.) The parts of this chapter that will most interest one-point modelers are the discussion of Kolmogorov's theories for the small-scale motion and the final section on rapid distortion theory (although it is discussed in more detail than modelers need).

Chapter 4: Second-order turbulence modeling. This refers mainly to stress-transport models, also known as second-moment closures, but with some discussion of algebraic stress models and other nonlinear eddy-viscosity models. The most common models, some of which are rather complicated, are discussed and summarized in a very helpful appendix. The main part of the discussion is rightly devoted to the pressure-strain redistribution term in the Reynolds-stress transport equations. (The dissipation equation and other equations providing a length scale were treated in the eddy-viscosity section of Chapter 2.) There is a short section on modeling the turbulent transport (diffusion) terms in the equations. A well-chosen eddy diffusivity seems to be adequate. It is, of course, a slight embarrassment that, having righteously abandoned eddy viscosity for the stresses, we still use it in the turbulent transport terms. The final section deals with intermittency modeling (the statistics of the turbulent/nonturbulent interface at the edge of the flow). The author states that the most important reason for studying this is the well-known inability of common turbulence models to get both plane jets and round jets right. Interface statistics are of particular interest in reacting flows in the case where one reactant is turbulent and the other is not.

Chapter 5: Turbulent two-dimensional shear flows. This 160-page chapter covers a wide variety of topics, too many to be summarized here. As usual, the discussion goes deeply into the subject, and data presented for the different kinds of shear layer include third- and fourth-order mean products and spatial correlations. Piquet does not disdain to present and discuss the empirical formulas used for growth rates and the like: of course most of these are for self-similar (self-preserving) flows. Jets, including wall jets, get much more space than boundary layers in zero pressure gradient!

Chapter 6: Complex effects in turbulent flows. This 250-page chapter is also difficult to summarize. The contents list includes a wide range of topics: two-dimensional boundary layers in pressure gradients, two-dimensional turbulent separation, classification of three-dimensional flows, three-dimensional turbulent boundary layers, curvature effects, rotation effects, lateral straining, imposition of sudden strains, roughness effects, freestream turbulence, and three-dimensional duct flow. As in the preceding chapter, the discussion includes plenty of data, but simple mathematics is used to stiffen the qualitative conclusions.

It may seem a little odd to put the physics (the last two chapters, which make up well over half of the book) after the modeling, but this does allow the formal processes of modeling to be described before confronting the reader with comparisons between models and data—and with the reasons why a universal turbulence model (other than the Navier–Stokes equations) is unlikely to be developed. The main omissions from this book, noted in the preface, are scalar transport (e.g., heat transfer) and the associated topic of the Lagrangian treatment of particle diffusion. The usual engineering models for heat transfer are closely analogous to models for momentum transfer, and discussing them would add little to the story. Sub-grid-scale models for large eddy simulations are also omitted, again without much loss to the narrative because present sub-grid-scale models are either highly specialized or extremely crude (to make them affordable). Apart from this, the treatment is very comprehensive.

With all due respect and admiration, one has to say that this book will probably tell any single reader (in aerospace or otherwise) more about turbulence than he or she wishes to know. There is so much detail that the unguided, inexpert reader, equipped only with the "introductory course in fluid mechanics" that is Piquet's prerequisite, is unlikely to get the overall picture. The modeler concerned with shear flows may not learn much from the discussion of spectral theory in homogeneous turbulence, and those who use spectral methods to study the fine structure of turbulence will probably regard one-point, Reynolds-averaged modeling as a rather low form of the art. However, this is an impressively comprehensive and authoritative reference book: it should certainly be in the library of any institution concerned with fluid mechanics and on the shelves of experts in the field who can lend it, with a reading list, to their students or juniors.

Peter Bradshaw
Stanford University

Liquid Cooling of Electronic Devices by Single-Phase Convection

Frank P. Incropera, Wiley, New York, 1999, 285 pp., $79.95

From time to time, a book is written that gathers information from various sources to serve a need. This book summarizes research results of experimental and computational studies spanning the past three decades. It is a useful reference for engineers considering design options in challenging electronic cooling problems and also can provide an overview for persons new to the field. The risk with any publication of this type, of course, is that parent papers will not be consulted and referenced by current-day practicing engineers and researchers for important details, caveats, and insights. With this cautionary note made, the book provides a convenient means to assess what is now known. Only convective heat transfer to liquids in the absence of boiling is considered. Omitted are numerous cooling options involving air, perhaps the most often preferred cooling medium in aerospace applications. Increasing power dissipation and decreasing device size may eventually make the use of liquids necessary even where air sources are readily available.

Where liquids are used in electronic cooling, some additional complexity is inherently introduced. Consequently, the author has focused on liquid cooling schemes that are more readily implementable and "rational" in his opinion. Novel techniques to enhance heat transfer, such as through acoustic means or flow and heat flux unsteadiness, have not been covered. The book has six chapters that include clear graphics and useful tables. Physical configurations are well defined, and numerous convective heat transfer correlations are provided. Symbols are discussed in the text or defined in a nomenclature list. Although few in number, worked example problems are given.

Chapter 1 provides an overview of configurations where liquids are used. These fall generally into situations where the liquid directly contacts electronic components or where heat transfer to the liquid is across physical barriers. A concise and readable summary of the fundamentals of heat transfer and fluid flow is given in Chapter 2. The summary includes information that can be found in most good heat transfer texts but is focused to support information provided in later chapters. Details about solution methodologies are largely absent. Natural convection, when tenable, is a preferred heat transfer mode in that cooling systems can be passive. Configurations that make use of this mode are appropriately presented next in Chapter 3. Experimental results are supplemented with computationally generated information for a variety of discrete heat source and cavity configurations. Chapter 4 concerns heat transfer from discrete heat sources to channel flows. Both mixed and forced convection are considered. It should be noted that results presented for specific configurations, particularly in Chapters 3 and 4, may not be readily extended to other configurations. Both experimental and numerical results will thereby be of most value in a qualitative sense. Readers are made aware of thermal resistances between the coolant and heat sources, and configurations that provide effective heat transfer are given as examples. Jet impingement cooling is the subject of Chapter 5. Because very thin boundary layers are developed and cooling can be localized to regions where heat is evolved, impinging jet flows are well suited for removing large heat fluxes, albeit often at increased system complexity. Convective heat transfer correlations for circular jets and planar jets are given for a variety of configurations. The implementation of liquid jets to cool simulated electronic packages is shown in several examples. The book concludes in Chapter 6 by highlighting means to enhance the heat transfer methods of Chapters 3–5. Engineers concerned with thermal management problems will find these techniques generally familiar. The usefulness of this chapter is mostly in placing into context the potential of enhancement schemes where the enhancements are derived chiefly from clever configuration improvements. For example, impinging jet flows can be combined with channel flows and extended surfaces to provide more uniform and enhanced heat transfer than is possible with single or multiple jets.

Although the reference list is lengthy, only a few papers that do not focus on electronic cooling are included. As such, papers of potential importance but of broader applicability may not be listed. Still, this book is a worthwhile addition to the personal library of any engineer involved in electronic cooling or other applications where similar concepts are pertinent. As stated by its author in his preface, the "book is intended to assist the engineer in developing suitable thermal management systems." It accomplishes this goal quite well.

David A. Zumbrunnen
Clemson University