AIAA JOURNAL
Vol. 46, No. 3, March 2008

Book Reviews

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Prediction of Turbulent Flows

Edited by G. F. Hewitt and J. C. Vassilicos, Cambridge University Press, New York, 2005, 343 pp., $175.

DOI: 10.2514/1.22439

THIS is a book of high-quality review articles by well-known experts in the subject.* The editors say it "evolved from" a summer program held at the Isaac Newton Institute (INI), Cambridge, England in 1999. It is not the complete proceedings of the program, and because "a very important feature was the involvement…of key players from industry" (and overseas), it is sad that all the authors but one are English academics. Chapter 2 (following a brief introduction by the editors) is a 45-page "summary of what is known about the nature of turbulent flows, particularly in the light of the work of the INI programme." It is an update of the paper by Hunt et al. ("Developments in Turbulence Research," *Journal of Fluid Mechanics*, Vol. 436, No. 1, 2001, pp. 353–391) and gives the titles and authors of some of the talks given at INI. Infuriatingly, the affiliations of those authors, which appear in abbreviated form in the *Journal of Fluid Mechanics* paper, have been deleted, perhaps by the press rather than by the chapter authors, and so it will be almost impossible for the reader to locate them unless she or he happens to refer to the journal paper. Granted that many of the talks may have been works in progress, one assumes that since 1999 most of them have now evolved into finished papers. Another unhappy result of editing is the accidental deletion from the list of references of the name of the late George Batchelor, to whom the chapter is dedicated. He and his pupils have had a great and lasting influence on basic research in turbulence.

Subsequent chapters are less closely connected with the INI program. The main account of the Reynolds-averaged turbulence models commonly used in industry is in Chapter 3 (79 pages), by B. E. Launder of Manchester. It is thinly disguised by the second part of the title "…flows affected by buoyancy or stratification," but of course, constant-density flows are a subset of these. The discussion refers mainly to two-equation models.

Another chapter with an important subset is Chapter 4 (35 pages) on turbulent flames, by W. P. Jones of Imperial College. The mythical gift of fire was the start of Bronze Age technology, but flows with effectively isothermal or constant-density reactions can be treated by the same models as combustion and commonly have simpler chemistry than the bedroom noises of hydrocarbon–air reaction equations.

Chapter 5 (44 pages) by J. F. Morrison of Imperial College bridges the gap between Prandtl's boundary-layer (thin-shear-layer) assumption and real-life flows in which those shear layers are often distorted. In steady laminar flows, this simply leads to regions in which the thin-shear-layer approximation has to be replaced by the Navier–Stokes equations or a better approximation thereto. In turbulent flow, large changes in turbulence structure can occur, to the bafflement of standard Reynolds-averaged turbulence models. Chapter 8 (52 pages) by J. C. R. Hunt and A. M. Savill of Cambridge is related and offers useful cautions to those wishing to use turbulence models in these difficult flows.

Various people who ought to know better have talked of turbulence as a great challenge to mathematics and physics. However, G. G. Stokes formulated the final form of the Navier–Stokes equations in 1845 (and the application of these equations to turbulence in Newtonian liquids and gases is now generally accepted). So the "turbulence challenge" is simply a problem in arithmetic (i.e., the problem of numerical solution of the Navier–Stokes equations). Even today, numerically exact solutions [direct numerical simulations (DNS)] for flows of engineering interest are too expensive in computer time, and so approximate methods based on qualitative understanding of the physics must be used. The first such methods were the Reynolds-averaged Navier–Stokes (RANS) turbulence models discussed in Chapter 3. More recently, large-eddy simulations (LES), in which the main eddies responsible for momentum and mass transfer are calculated exactly and only the small eddies are modeled, have been extended to engineering flows in the hope of better accuracy than with RANS models. However, flow near a rigid surface, in which all the eddies are small, is still a critical modeling problem, and most of the models are even less refined than RANS, exactly when more refined models are needed. The present state of simulations, both DNS (numerically exact) and LES, is discussed in Chapter 6 (29 pages) by N. D. Sandham of Southampton. Development of direct simulations depends on reduction in computing costs and, to a smaller extent, on improved numerical methods for complex

*Received 13 January 2006; accepted for publication 3 February 2006. Publication was delayed due to production difficulty.

flows. Large-eddy simulation for wall-bounded flows will be similarly restricted unless there is a breakthrough in near-wall modeling. In the foreseeable future, flow over large-scale bodies such as aircraft or their engines will have to be computed by a combination of RANS, LES, and DNS. Combustion models fitted to one of these schemes will be needed. Chemical reactions, including combustion, require mixing of reactants down to the molecular scale. Despite this, large-eddy simulation (in which the spatial resolution is orders of magnitude larger than that of the smallest turbulent eddies, which is in turn much larger than that of molecular mean free paths) has given useful results.

Chapter 7 (55 pages) by G. F. Hewitt (Imperial College) and M. W. Reeks (Newcastle) discusses multiphase flows, which is a vital part of chemical engineering, for example, in fluidized reaction beds and in the combustion of sprays of liquid fuel or pulverized solids. Like most of the remaining vital problems, it is a very difficult one, the nonlinear processes making simple Reynolds averaging inadequate. It is probably today's most severe challenge to turbulence modeling.

The authors of the different chapters differ in their efforts to update their articles between the 1999 INI program and the 2005 publication date. However, this volume is a good introduction to turbulence research at the start of the 21st century, and each chapter is well-supplied with references, although naturally it is assumed that the reader knows the basics of the subject. The book presents a more measured view than a conference proceedings volume of unrelated papers can possibly do and also presents a much broader picture than some recent books with one or two authors, which naturally concentrate on those authors' views. Whether turbulence is a challenge to mathematics, physics, or computing, it is a challenge in engineering, earth sciences, and astrophysics and will probably remain so during the lifetime of this book's readers.

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