Book Reviews

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Ten Chapters in Turbulence

P. A. Davidson, Y. Kaneda, and K. R. Sreenivasan (eds.), Cambridge University Press, Cambridge, England, U.K., 2013, 437 pp., $99.

DOI: 10.2514/1.J052847; published online 31 January 2014.

This interesting volume is an outgrowth of the Workshop on Inertial-Range Dynamics and Mixing held in the fall of 2008 at the Isaac Newton Institute in Cambridge. As the title indicates, it consists of 10 independent chapters, each written by prominent turbulence researchers. The preface includes musings on the difficulty of the subject and the hope for a satisfactory theory.

Chapters 1–4 focus on different aspects of homogeneous, isotropic turbulence (HIT), with the information presented coming principally from direct numerical simulations (DNS). In Chapter 1, Kaneda and Morishita review our knowledge of velocity statistics and how they relate to the Kolmogorov hypotheses and other basic theories. In Chapter 2, Schumacher et al. examine vorticity from several perspectives, including the behavior of velocity-gradient invariants; the development of finite-time singularities in inviscid flow and intense vorticity in viscous flow; and the extraction of vortical structures using wavelets and curvelets. In Chapter 3, Gotoh and Yeung review our knowledge of the statistics of conserved passive scalars, and in Chapter 4, Sawford and Pinton review Lagrangian statistics related to turbulent dispersion. A clear message from these four chapters is that DNS of HIT can now reach sufficiently high Reynolds numbers to address most questions of practical and theoretical interest. For most statistics, the Reynolds number scalings and the high-Reynolds-number asymptotes have been determined.

Chapters 5, 6 examine simple wall-bounded flows. In Chapter 5, Marusic and Adrian consider the three canonical wall-bounded flows: pipe flow, channel flow, and the flat-plate boundary layer. The emphasis is on the scaling of the mean velocity and Reynolds stresses and on the different vortical structures that have been observed. For the most part, the information reported comes from particle image velocimetry. In Chapter 6, Jimenez and Kawahara again examine wall-bounded flows, but now relying almost exclusively on DNS. They make the point that an advantage of DNS is that one can perform numerical (i.e., nonphysical) experiments, for example by computing wall-bounded flows using a periodic box of limited extent, and this helps to elucidate the underlying physics. The authors conclude that turbulence research has crossed an important threshold: for the canonical flows, thanks to DNS, we now have essentially all of the information we need to develop and test theories and models. This includes simulations with a sufficient range of scales to determine Reynolds-number scalings.

Chapters 7–9 examine our knowledge of turbulence subjected to strong body forces, namely buoyancy, Coriolis, and Lorentz forces, respectively. In Chapter 7, Riley and Lindborg review recent work on turbulence in stably stratified flows, at high Reynolds number and low Froude number. They develop scaling arguments for different turbulence statistics, which are much more complicated that in nonstratified flows, because the turbulence is highly anisotropic, and there are additional scales (e.g., the Ozmidov scale) and parameters (e.g., the buoyancy Reynolds number). The authors carefully review data and understandings obtained from DNS, from laboratory experiments, and from field measurements in both the atmosphere and the oceans. The picture that emerges is that the scaling laws developed are successful in accounting for the data (especially spectra) over this broad range of flows. In Chapter 8, Davidson examines rapidly rotating turbulence, which is dominated by cyclonic columnar vortices parallel to the axis of rotation, and associated inertial waves. The three main questions addressed are as follows. By what mechanism do the columnar vortices form? Why are they dominantly cyclonic? And how does rotation influence the rate of decay of energy? In contrast to the previous chapters, here the investigations do not provide clear, consistent answers. Furthermore, experimental and numerical studies provide different pictures because the systems studied are different. In Chapter 9, Tobias et al. provide an accessible review of magnetohydrodynamic (MHD) dynamos and turbulence. Compared to Chapters 7, 8, two important differences are that, here, the magnetic field and the electric current (producing the Lorentz force) are coupled to the velocity field, and that the Lorentz force affects the motions even on the smallest scales. Interestingly, in different cosmological occurrences of MHD, the magnetic Prandtl number is either large or small, but not close to unity. On the other hand, numerical simulations become progressively challenging as this Prandtl number departs from unity. Even so, because observations and laboratory experiments are so difficult and limited, computer simulations provide the main tests for the competing theories. For the flows considered in these three chapters, DNS is again providing valuable insights and statistics, but because of the additional scales introduced by the body forces, significantly more computer power is needed, and it will be several decades before the simulations can access most of the parameter range of interest.

In the final chapter, Skrbek and Sreenivasan explore some similarities between quantum turbulence (QT) and regular homogeneous, isotropic turbulence (HIT). Quantum turbulence occurs in certain cryogenic fluids and can be viewed as a state of two interpenetrating fluids: the normal fluid governed by the Navier–Stokes equations, and the inviscid superfluid, which tends to form line vortices. Similarities are observed between spectra and decay rates measured in QT and HIT.

Overall, this volume provides a useful review of the state of the art in the fundamental areas covered. Three aspects of the turbulence "problem" are obtaining empirical knowledge about statistics and structures; developing theoretical understanding (ultimately from the Navier–Stokes equations) on why these quantities are the way they are; and developing predictive models for turbulent flows and processes within them. We can continue to lament the slow progress on the latter two aspects, but this book is in part a celebration of the fact that, primarily through DNS, the first aspect of the problem is largely solved (at least for simple flows).

The production of the book by Cambridge University Press is a mixed bag. In general the appearance is attractive, and in some chapters, we are treated to color figures, even for line drawings. On the other hand, there are some significant typographical errors (e.g., the very first equation, the Navier–Stokes equation, lacks an equals sign), and some other figures are of poor quality (e.g., Fig. 8.7).

Stephen B. Pope
Cornell University