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BOOK REVIEW

Homogeneous Turbulence Dynamics (2nd edition). By Pierre Sagaut and Claude Cambon. Springer, 2018. 912 pp. ISBN: 978-3-319-73161-2 (print) £244.50; ISBN: 978-3-319-73162-9 (ebook) £195.50.

In his 1932 address to the British Society for the Advancement of Science the famed mathematician Sir Horace Lamb was said to have made the following seemingly prescient statement:

> 'I am an old man now, and when I die and go to heaven, there are two matters on which I hope for enlightenment. One is quantum electrodynamics and the other is the turbulent motion of fluids. About the former, I am really rather optimistic'.

Turbulent flow is a ubiquitous aspect of nature and its understanding has important implications for a wide variety of applications including weather prediction, industrial flows and aeronautics. Increasingly detailed and precise experiments combined with highly resolved numerical simulations have led to some insights, but despite over 100 years of research a full understanding of the detailed mechanics of turbulence and its implications for quantities of applied interest such as drag, lift and mixture fraction remains incomplete. For example, as understood by G. I. Taylor, an important goal is to predict the statistics of a turbulent flow. Even under simplifying assumptions that the statistics are homogeneous (i.e. invariant under translation) and isotropic, we still do not have satisfactory theories for the formation and maintenance under large scale forcing of the so-called inertial range Kolmogorov energy spectrum. We have a lot of what Philip Saffman termed 'postdictions' but very few real predictions. Homogeneous isotropic turbulence is an idealization and in real flows one must contend also with sources of anisotropy such as rotation, stratification or shear, as well as inhomogeneity arising from geometry as occurs for example in boundary layers. Nevertheless, there has been important progress in all areas.

In this book, Drs Sagaut and Cambon, who have made important contributions to the field, summarize this progress for homogeneous turbulence in the absence of isotropy with a particular focus on dynamics, that is, the use of the nonlinear equations of motion combined with closure or other simplifying assumptions to make predictions on important statistical quantities that in turn can be used to compute large scale flow diagnostics. This text builds on an earlier edition published by Cambridge University Press in 2008 and expands on it considerably. After summarizing to the reader the required mathematical machinery used to explore both incompressible and compressible homogeneous turbulence, the authors then provide discussions of important special cases, proceeding from the basic, though still not completely understood, topic of homogeneous isotropic turbulence to more complex anisotropic flows arising from rotation, shear and stratification. Throughout their discussions they compare theoretical results to existing experimental and computational results. Several additional topics are introduced in this edition: dynamics of 'quantum' turbulence associated with superfluids, turbulence in the presence of viscoelastic polymer additives and magnetohydrodynamic turbulence. Underscoring the level of scholarship evident in the present work is its synthesis of the vast literature that characterizes the various topics. Each chapter ends with a detailed bibliography referencing important early as well as contemporary work.

After introducing the incompressible and compressible Navier–Stokes equations and some of the mathematical tools associated with their analysis as used in this book, the authors begin in Chapter 4 by considering incompressible homogeneous isotropic turbulence with a fairly comprehensive (and rapid) review of the various theoretical approaches. This chapter discusses important classical results such as the Kolmogorov energy cascade in the inertial range and the 4/5 law. Such results for homogeneous isotropic turbulence are presented in the Fourier basis and are typically described via interactions of wave triads, but the authors also attempt to provide physical descriptions, in particular making contact with the important work of Waleffe and others on triad instability. An important issue is what physical processes correspond to the cascade (and also account for intermittent effects). This problem is still an area of active research and the authors present a through discussion.

The next two chapters are new in this edition. Chapter 5 discusses turbulence in dilute polymer solutions. Owing to the non-Newtonian response of the polymer at small scales, several scale-dependent regimes appear, even in isotropic turbulent flow depending on the various characteristic time scales of the polymer and flow response. Chapter 6 considers so-called ‘quantum’ turbulence associated with the various turbulent phenomena observed in superfluid helium. Here the small scale structure differs from that of Newtonian fluids in that such flows display quantized vortices structured as filaments. These vortices are not classical, but it is of interest to study disordered structures that arise as a result of their mutual interaction. The theoretical approach here differs somewhat from classical turbulence involving the Gross–Pitaevski equation, valid at zero temperature. There are important connections with the Navier–Stokes equations through the Madelung transformation and vortex dynamics using the Biot–Savart law. The study of polymer and quantum turbulent flows may eventually shed some light on small scale turbulence in classical fluids, but, as the authors point out, further work is required to establish clearly such connections. In any case both these chapters provide a very good overview of areas not typically discussed in treatments of turbulence, again with a very thorough review of the existing literature.

The next five chapters, Chapters 7–11, are concerned with incompressible turbulence in the presence of anisotropic forcing. Chapters 7–10 consider the effect of a single type of forcing, respectively rotation, strain, shear and stratification. Chapter 11 considers turbulence coupled with various combinations of all these forcings which arises, for example, in geophysical applications. Where such forcings are stabilizing, the energy transfer in the turbulent flow is at least partially mediated through the interaction of wave-type solutions and the cascade of, for example, kinetic energy is significantly modified. Here it is possible to use the rotation, stratification, shear, etc. as a type of control parameter to inhibit or promote various energy transfers. Key tools in this analysis make use of what is known as rapid distortion theory (RDT) where linear terms dominate the dynamics. Where nonlinearity becomes important, closure techniques such as the eddy damped quasi-normal Markovian approach (EDQNM), a mainstay of the present volume, can be used. Unfortunately, the technical aspects of these approaches are somewhat interspersed throughout other chapters and so this makes for a somewhat disjointed presentation. Nevertheless, these chapters convey the important phenomena. More importantly they also make contact with more recent work on transient growth, elliptic instability, as well as relating the modal dynamics to the important self-sustaining processes evident in many turbulent flows. Finally, turbulence in the presence of unstable stratification (Rayleigh–Taylor instability) is explored. For weak stratification (i.e. the Boussinesq limit) some progress is possible using tools such as RDT and EDQNM, but for stronger stratification the flow becomes inhomogeneous and modelling such flows is still done using simpler models of buoyancy and drag calibrated to experimental data.

Chapter 12 is again a new chapter examining incompressible homogeneous turbulence in the presence of magnetohydrodynamic effects. The presence of a magnetic field in a conducting fluid allows for the opportunity to control the level of nonlinearity and even the effective spatial dimension. The authors provide a cogent summary of previous results as well as a discussion of prominent open problems.

Chapters 13–15 consider turbulence in the presence of compressibility. When such effects are included, new pathways of energy transfer become possible through acoustic and entropic contributions that interact with the classical vortical dynamics associated with incompressible turbulence. The authors approach this still emerging field in stages. They begin by considering isotropic turbulence in the presence of weak acoustic perturbations. This produces the possibility of equilibrium between dilational and solenoidal disturbances in the linear approximation, with more complex interactions when weak nonlinearity is considered. A discussion is also provided of the production of noise by quasi-isentropic isotropic turbulent flows as pioneered by Lighthill. As the Mach number of the turbulent fluctuations increases, new phenomena appear in the form of localized shock waves (known as shocklets). These provide a distinct pathway at small scales for energy dissipation and the authors describe ongoing work on statistically accounting for their occurrence. The effect of compressibility on turbulent shear flows is described next in accord with the book's emphasis on anisotropic effects. In general, it is seen that compressibility acts as a stabilizing effect, as seen, for example, in the decreased growth rate of compressible turbulent shear layers. However, the authors describe situations in which it is possible to increase kinetic turbulent energy locally as a result of compressibility effects. Here it would have been helpful to attempt to summarize and quantify better the regimes where such intensification is expected to happen. Finally, the case of turbulence interacting with a normal planar shock is considered. Such flows occur in a number of important applications, for example, scramjet propulsion as well as inertial confinement fusion. In the linear regime, the key tool is the use of Ribner's linear interaction approximation (LIA) which decomposes the flow into acoustic, entropic and vertical disturbances and then analyses how such modes are processed by a shock wave. While LIA provides a reasonable approximation for low turbulent Mach numbers and weak to moderate shock waves, there are interesting nonlinear effects arising from the amplification of the vorticity by the shock. As the turbulence intensity increases the curvature of the shock wave can be strongly affected and in extreme cases, the shock wave can be disrupted.

Chapters 16 and 17 are devoted to a more detailed assessment of the various theoretical approaches that were applied in the previous chapters. This is a very technical subject and well-described here, but again, it would have been useful to have the key aspects of these various approaches at least summarized when they are needed in the earlier chapters. On the other hand, the authors effectively present the levels of complexity of the various approaches making the important point that the impact of the various closure schemes can now be examined even for anisotropic turbulence as a result of progress in optimizing their numerical simulation.

Finally, Chapter 18 provides conclusions and perspectives. The authors indicate that there has been important progress in many areas, particularly as numerical simulations and experimental diagnostics achieve finer resolution, and they have effectively presented in this work the developments associated with inclusion of anisotropy. At the same time, they note rightly that there is significant room for progress, as these important theoretical developments have not yet had as much impact as one might desire on the modelling of turbulence for flows where the assumptions of isotropy and homogeneity are of limited applicability. There remain too important problems of how to deal with issues of spatial and temporal intermittency and how to properly merge the point of view of coherent structure dynamics with statistical closures of the Navier–Stokes equations.

The authors have essayed to make it possible to read their work at two levels, the first for those who want to survey results but who are not as interested in the detailed analytical tools, and the second for those who wish to delve more deeply into the details. They are not completely successful here, as it is sometimes difficult to see the delineation between basic and advanced material. As stated above, the authors also describe the various theoretical tools being used in the latter chapters of the book. The intent is to relegate these more complex topics to the end, but they are often mentioned in the various discussions with forward references. It would have perhaps been better to recapitulate some foundational technical results as part of the basic discussions. In addition, in the electronic version of this book results from other chapters are referenced but it is not possible to link back to these because the book has been formatted by the publisher (Springer Verlag) as a set of individually downloadable chapters rather than one fully linked text.

Finally, it should also be mentioned that this book is most likely not appropriate as an introductory text. Rather, it is an excellent follow-up for those who have gotten an overview from more general texts such as those of Tennekes and Lumley or Pope. The real strength of this text is the presentation of a variety of technical viewpoints and its expansive coverage of both the incompressible and compressible turbulent regimes while surveying effectively the vast literature of the field. The first edition of this text had as its cover illustration an image of the Tower of Babel painted by Breughel the Elder, an apt description of the diversity of often non-intersecting approaches in turbulence research. The authors have taken an important step forward in this edition by showing the similarities and differences among these approaches while laying out a path towards future progress by calling attention to the remaining open problems.

Dan Meiron
California Institute of Technology