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REVIEWS

A First Course in Turbulence. By H. TENNEKES and J. L. LUMLEY. M.I.T. Press, 1972. 300 pp. $12.50.

Random Functions and Turbulence. By S. PANCHEV. Pergamon, 1971. 444 pp. £7 or $18.75.

Teaching what little is understood about turbulence to graduate or undergraduate students presents great difficulties to the lecturer. It is not at all easy to decide which are the most important ideas and results to convey, in which order to teach the material, how elaborate the mathematical treatment need be, what previous knowledge to assume in the student, and which introductory books, if any, are appropriate. Tennekes and Lumley aim to provide such an introduction to final-year undergraduates or first-year graduate students. They are to be congratulated in helping to bridge the gap between the introductory fluid dynamics text which may make some mention of turbulence, especially in engineering text books where turbulent boundary layers and pipe flows are treated, and the advanced monographs and text-books such as those of Batchelor (1953), Townsend (1956), Hinze (1959) or more recently Monin & Yaglom (1971).

In considering this book by Tennekes and Lumley it is useful to note that it attempts "to avoid a bias toward any specific discipline", but also attempts to avoid "advanced statistics and Fourier analysis". This has some disadvantages as well as advantages because students from different disciplines have covered quite different aspects of fluid mechanics before tackling such a course. For example, many engineering graduate students (at least in the U.K.) are broadly familiar with calculating turbulent boundary layers while being quite unfamiliar with the physical ideas of turbulence, the manipulation of tensors and probability theory. On the other hand, more mathematical graduate students trained in classical fluid mechanics do not have any knowledge of turbulence in any form, but should be happy to deal with the mathematical tools of turbulence theory even if they are not familiar with them. It is bearing in mind these two types of student that one seriously questions the choice and the ordering of the material in this book. At some places the latter is sufficiently eccentric that one wonders if one author wrote chapters 2–5, another chapters 6–8, and both wrote chapter 1. The outstanding example of this is that Kolmogoroff's hypotheses and the idea of the energy cascade are only properly described in chapter 8, yet the Kolmogoroff microscale is briefly introduced in the introductory chapter 1 (which includes the welcoming words "non-linear stochastic system"), and is used in chapter 3 on "the dynamics of turbulence" and in chapter 5 on "the wall bounded shear flows". One cannot help thinking that the authors would have been wiser to have described the salient phenomena of homogeneous turbulence before plunging into shear-flow turbulence, and followed the well-trodden path of Landau &

Lifshitz, Townsend, and Hinze. This is particularly true for engineering students, for whom chapters 6–8 give the really new insight into turbulence. If these chapters had come earlier, they would then be able to look at shear-flow turbulence with fresh eyes. For more mathematical students, the implicit use of unfamiliar ideas which come later in the book must be confusing.

Turning now to more detailed comments, the page or two in chapter 1 devoted to transition from laminar to turbulent flow is very brief. Surely no textbook is now complete without some discussion of 'fast' and 'slow' transition or Landau's description of breakdown from one instability to many. A thorough description of transition can give students valuable insight into the nature of turbulence. Otherwise this chapter is a useful introduction. The second chapter on the "turbulent transport of momentum and heat" describes how molecular action produces viscous stresses in a shear flow, and then goes on to show why the same analysis is not physically valid for calculating shear stresses in a turbulent flow. Here again the ordering of the material is puzzling because ideas of vortex stretching and integral time scales are used before later chapters on the dynamics and the statistical description of turbulence. The third chapter on dynamics introduces the turbulent energy equation; production, dissipation and thence (again) the Taylor and Kolmogoroff microscales. Vorticity dynamics are usefully covered in a way that has not been included in any text before, in particular with an example of vortex stretching by the mean motion in wind-tunnel contractions and with a discussion of the terms in the equation for the mean-square turbulent vorticity, namely vortex stretching by the turbulent motion and viscous dissipation. However, there seems to be no clear mention of the interesting physical argument that $\overline{\omega_i \omega_j (\partial u_i/\partial x_j)}$ is positive because two particles on average move apart from each other and therefore vortex lines are on average stretched rather than compressed.

Chapters 4 and 5 on boundary-free and wall-bounded turbulent shear flows are in the spirit of Townsend's book, but are a better introduction to the theory of these flows, because the authors explain more explicitly than Townsend the assumptions and the mathematical reasoning of these theories, in particular the ideas of self-preserving and, following Clauser, equilibrium flows. It is disappointing that there is no mention of the advances which have been made during the last six years in understanding the mechanics of turbulent boundary layers, stemming from the work of Kline and Reynolds in particular. The physical picture provided by these experimental investigations is so illuminating that perhaps it ought to be mentioned even at the level of this book. Chapter 6 gives an excellent introduction to the "statistical description of turbulence" with some first-class diagrams. It is obviously a matter of choice whether characteristic functions are taught at this stage, presumably the reason here is that they are used to give a simple proof of the central limit theorem. The ergodic theorem is discussed, although the production of examples of random functions which do not satisfy the theorem would have helped to clarify its meaning. Chapter 7 on "turbulent transport" does not provide the simplest of introductions, but does go on to explain clearly how turbulent straining in conjunction with molecular diffusion accelerates diffusion. Chapter 8 on "spectral dynamics" is the one which one might think should be near the beginning. But having reached it, or skipped to it, the student will find a good account of the energy cascade, the role of large eddies in straining the vorticity of small eddies, and the inertial and viscous subranges. No mention is made here or elsewhere of the structure function. The chapter concludes with a description of temperature spectra. Here and elsewhere the effects of turbulence on heat transfer are mentioned. Indeed in chapter 3 magnetohydrodynamic effects are introduced.

An excellent feature of the book is the collection of problems at the end of each chapter. In conclusion, one would certainly recommend that all libraries should have a copy of this book on account of the many useful introductory insights into turbulence. But one would only recommend students to buy this book if the choice and order of material in their course were something like that in this book.

Panchev's book is aimed at a different audience in that it is part textbook and part research monograph (it appears in Pergamon's international series of monographs in natural philosophy). The book is written for graduate students and research workers in applied mathematics, hydrodynamics and meteorology, and is intended "primarily as an introduction to the statistical theory of turbulence".

The book has three parts. Part I introduces the theory of random functions to students of turbulence theory. Chapter 1 is a straightforward and useful introduction to the theory of probability, with the salient formulae given for normal distributions and characteristic functions. Here and elsewhere there is less graphical and physical discussion than in Lumley's book "Stochastic Tools of Turbulence", but the mathematics is more straightforward. Chapter 2 on "random processes" is particularly good in explaining stationary random functions and ergodicity. Generalized harmonic analysis and Fourier–Stieltjes integrals are satisfactorily treated. But a thoroughly misleading impression is given in §8 about turbulence having an approximately normal joint probability distribution. The chapter concludes with a brief and incomplete discussion of the error in handling data. Chapter 3 on "random fields" is a good introduction to moments and their form when isotropic so that a student could follow the treatment without constantly having to refer to other texts. Then the standard relations for first-, second- and third-order correlations and spectra are derived for homogeneous and isotropic fields. The notation and terminology is different from that of Batchelor (1953). A number of worked examples are given, for example calculating the energy spectrum tensor from a cross-correlation in isotropic turbulence.

In the second part, "Hydrodynamic turbulence", the reader is introduced to the mathematical description of turbulence, using the mathematics developed in the first part. However, this part begins with a most confusing chapter 4 which opens with dimensional analysis, continues with a brief, superficial discussion of transition including the effects of stratification, and then plunges into Kolmogoroff's hypothesis and Obukhov's extension to include temperature fluctuations. Chapter 5 is an extensive account of the equations governing correlations, with little physical discussion. Sections 2 and 3 on Loitsianskii's invariant and the various rates of decay of homogeneous turbulence are particularly bad. But results for correlations of pressure, acceleration and temperature using Millionshchikov's hypothesis are fully derived and some useful comments are made. Chapter 6 on the spectral analysis of turbulence and the equations governing spectra also becomes bogged down with manipulation, so that the physical ideas of the energy cascade are not explained well. The author cannot resist giving an extended account of the various theories of transition between the inertial and viscous subranges, which are shown by the diagram on p. 244 to be all quite similar. Chapter 7 contains some miscellaneous topics, including a brief and indifferent discussion of turbulent diffusion, and review of the recent work by Kolmogoroff, Yaglom and others on the consequences of the energy dissipation being a random function.

Part III is an account of recent research on atmospheric turbulence, with particular reference to research in Eastern Europe and the Soviet Union. Chapter 8 on "small-scale atmospheric turbulence in the lower atmosphere" reviews experimental and theoretical work on spectra and correlations with and without temperature effects. The author demonstrates the power of similarity and dimensional analysis, but does not follow this up with a discussion of the physical implications. Chapters 9 and 10 on "large-scale atmospheric turbulence" and "numerical weather analysis and prediction" are primarily mathematical and tough going for someone (like myself) not familiar with these applications of the ideas of turbulence theory.

In conclusion, Panchev's book can be recommended as a good introductory account of the theory of random functions, which research workers in turbulence may also find useful as a reference for the more unusual points of the theory. But it cannot be recommended as an introduction to the physical ideas of turbulence theory. However, for both the first part and the account of fairly recent research on atmospheric turbulence in the third part, one would strongly recommend libraries, and perhaps the odd opulent individual, to buy a copy.

J. C. R. HUNT

Coronal Expansion and Solar Wind. By A. J. HUNDHAUSEN. Springer-Verlag, 1972. 238 pp. DM 68 or $21.60.

This research monograph begins with a brief historical review of the ideas that led up to the theory of coronal expansion and the solar wind. It covers the various formulations of coronal expansion that can be found in the literature – the one-fluid models, two-fluid models, the evaporative models, etc., and goes on to discuss the variations in the solar wind, from the small time scale of the proton cyclotron period (about one second) to the variations in the overall period of coronal expansion (in times of several days).

Coronal expansion and the solar wind has proved a continuing challenge to the fluid dynamicist and plasma physicist. The problem begins with the generation of hydromagnetic, sound and internal gravity waves beneath the solar photosphere. Their passage outward through the corona is responsible for the intense – and occasionally explosive – heating of the corona. The resulting coronal expansion in the strong gravitational field of the Sun – with the gravitational field playing the role of the constricted throat in a Laval nozzle – leads to the supersonic solar wind. Many of the time and space variations in the wind are now observed in detail and have succumbed to the attacks of the theoretical fluid dynamicist. But there remains much to be done, and the small-scale plasma physics problems have just begun.

There is a curious observational problem that arises in discussing the variations in the wind. The more vigorous variations in the solar wind plasma propagate through the plasma at about the Alfvén speed V_A and/or the speed of sound V_S, typically 50 km/s, while the wind carries the phenomenon past the observing spacecraft with a speed v which is about ten times greater than V_A or V_S. Thus an active phenomenon with a characteristic length λ and time τ in the wind is carried past the observer in a time $t = \lambda/v$. One observes t and uses the relation $\lambda = vt$ to deduce the scale λ, but obtains no direct information on τ from the observation. Hundhausen adroitly handles this difficulty, first making clear the difference between the observed and the actual time scale of the phenomenon, and then relating the various scales to the appropriate physical effects, such as the proton cyclotron period, hydromagnetic waves, sectors and streams, etc.

There are a number of basic questions concerning the spatial extent of the heating of the solar corona, the helium abundance in the wind and its relation to the solar abundance of helium, the abundance of highly ionized heavy atoms in the wind, the rotational discontinuities in the wind, the occasional blast waves from the Sun, the relation of the magnetic sectors to features on the surface of the Sun, etc., which have proved difficult to resolve. These phenomena have been explored both observationally and theoretically, leading to various explanations and conclusions. The book is noteworthy for a thorough, critical, and dispassionate review of these difficult topics.

Particular attention is given to the structure of the rotating magnetic sectors and to the blast waves associated with flare activity. Not only are these interesting from a purely intellectual point of view, but they are of enormous practical importance as well. There is a growing body of evidence accumulated over the last fifty years that both local and worldwide weather activity is connected in some obscure way with the activity of the Sun, and more closely in some cases with the activity of the geomagnetic field. The connexion is evidently through the solar wind, particularly the active or non-uniform wind. Chapters V, VI, and VII summarize current knowledge of the active solar wind and form a point of departure for thinking about geomagnetic activity, auroral particle precipitation, the dynamical fluctuations of the geomagnetic tail, etc., which evidently play the basic role in the solar and terrestrial weather connexion.

Altogether the monograph is a concise, scholarly and critical review of present-day knowledge and understanding of the solar wind, including its origin at the Sun, its variations over space and time, its composition, and its remaining mysteries. The list of references is thorough. The text is readable. It is the opinion of this reviewer that it will become the standard reference and research monograph on the solar wind.

E. N. PARKER

SHORTER NOTICES

Annual Review of Fluid Mechanics. Volume 5. Edited by M. VAN DYKE, W. G. VINCENTI and J. V. WEHAUSEN. Annual Reviews Inc., 1973. 443 pp.

On scanning the contents of the fifth volume of this series, which is henceforth to be published each January, one immediately notices that it contains many more experimentally oriented contributions than previous volumes. There is an accompanying increase in the number of plates, including some beautiful coloured flow visualizations photographed in the ONERA wind-tunnel. The articles, which are somewhat more specialized than many that have appeared in the past, will enable readers to increase their knowledge in a number of well-established areas of fluid mechanics.

The list of contents reads as follows.

Ludwig Prandtl in the nineteen-thirties: reminiscences, Irmgard Flügge-Lotz & Wilhelm Flügge.
Use of lasers for local measurement of velocity components, species densities, and temperatures, S. S. Penner & T. Jerskey.
Experiments in gasdynamics of explosions, A. K. Oppenheim & R. I. Soloukhin.
Longitudinal dispersion and turbulent mixing in open-channel flow, Hugo B. Fischer.
Spherical-cap bubbles, Peter P. Wegener & Jean-Yves Parlange.
Intermittency in large-scale turbulent flows, Erik Mollo-Christensen.
Transonic airfoils: recent developments in theory, experiment, and design, G. Y. Nieuwland & B. M. Spee.
Buoyant plumes and wakes, James A. Fay.
Hydrofoils and hydrofoil craft, A. J. Acosta.
The fluid mechanics of lubrication, E. A. Saibel & N. A. Macken.
Instability, transition, and turbulence in buoyancy-induced flows, B. Gebhart.
Secondary flows: theory, experiment, and application in turbo-machinery aerodynamics, J. H. Horlock & B. Lakshminarayana.
Noise from aircraft turbomachinery. James E. McCune & Jack L. Kerrebrock.
Mixing-controlled supersonic combustion, Antonio Ferri.
Three-dimensional boundary layers, E. A. Eichelbrenner.
Hydrodynamic flow visualization, H. Werle.
Molecular gas dynamics, M. N. Kogan.
Prandtl's boundary-layer theory from the viewpoint of a mathematician, Karl Nickel.

Proceedings of the Third International Conference on Numerical Methods in Fluid Mechanics I. General Lectures, Fundamental Numerical Techniques. Edited by H. Cabannes and R. Teman. Springer-Verlag, 1973. 186 pp. $6.40.

Proceedings of the Third International Conference on Numerical Methods in Fluid Mechanics II. Problems in Fluid Mechanics. Edited by H. Cabannes and R. Teman. Springer-Verlag, 1973. 275 pp. $9.20.

These two volumes (Volumes 18 and 19 in the series 'Lecture Notes In Physics') follow the precedent established by the publication in 1971 of the Proceedings of the Second International Conference on Numerical Methods in Fluid Mechanics as Volume 8 in the same series. The reproduction is again by photographic procedure from submitted papers. The Third Conference was held at the University of Paris VI from 3 to 7 July 1972, and the editors are to be congratulated on making the Proceedings available (at a price) so soon. Volume I contains the text of three general lectures and thirteen short papers on fundamental numerical techniques. Volume II contains thirty-five papers on 'problems of fluid mechanics', the emphasis being again of course on the numerical aspects. A few of the papers are in French, the rest in English.

On the Birth of Boundary Layers. By J. Grasman. Mathematical Centre Tracts 36, Mathematisch Centrum Amsterdam, 1971. 137 pp. Benelux fl. 15 or $5.

This monograph is an account of the rigorous asymptotic theory of elliptic differential equations containing a small parameter. An illustrative example is taken from the theory of magnetohydrodynamic flow through circular pipes at large Hartmann number. Of special interest to the readers of this journal is that the author substantiates the validity of the intuitive singular perturbation approach to these problems used by Shercliff (1962, *J. Fluid Mech.* **13**, 513) and Roberts (1967, *Proc. Roy. Soc.* A **300**, 94). Further, it is conceivable that his approach may be generalized to include nonlinear equations, with important consequences for the whole singular perturbation theory of fluid mechanics.