REVIEWS

Non-Newtonian Fluids. By W. L. WILKINSON. London: Pergamon Press, 1960. 138 pp. 37*s*. 6*d*.

The need to study and explain the behaviour of anomalous, or non-Newtonian, fluids has been evident for many years. Nevertheless this study has so far remained almost a backwater of mechanics, and finds no place in formal teaching courses. This has been largely because of the great difficulties inherent in the mathematical formulation of the behaviour of any non-Newtonian fluid system; lack of a suitable theoretical background has hampered the systematic collection of experimental evidence on which the validity of any theory must ultimately rest.

The situation is further complicated by the enormous range of types of anomalous behaviour that have been observed, and by the variety of effects that result. The distinction between solids and fluids ceases to have any clear-cut significance. Hence categorization and suitable specialization become problems in themselves. This circumstance cannot be avoided by any author attempting to treat the subject, even though the normal restrictions of space may cause him to treat fully only a limited selection of individual topics.

The book under review has been written by a chemical engineer for students of chemical engineering. As such it fulfils its purpose very adequately; it will also be found very useful by non-specialists as an introduction to the simpler concepts and elementary mechanical principles of non-Newtonian flow. These obvious merits imply in this case a degree of superficiality: because of the undoubted problems that arise in a more comprehensive mechanical treatment of non-Newtonian flow, a critical account of the several chapters of this book is given below.

The first chapter is concerned, necessarily, with the classification of non-Newtonian fluids. The terminology adopted is as conventional as it could be, given the present stage of development of the subject; but this does not mean that it is a satisfactory terminology or that it is exhaustive. In particular, the author limits himself to a discussion of stress *vs* rate of strain laws for various bodies in *plane shear* only. Unfortunately this method fails to distinguish between many fluids of very different mechanical properties, properties—such as 'cross-elasticity'—which give rise to very different behaviour in more general types of flow (e.g. flow with a free surface, or flow past an obstruction). This severe limitation is maintained throughout the book; it is perhaps arguable that such a restriction is justified in a monograph for chemical engineering students, where the main application is to pipe flow, but the author should have made abundantly clear its restrictive nature. Mention should have been made of the results, if not the methods, of Oldroyd (*Proc. Roy. Soc.* A, **200**, 1950, 253), Truesdell (*J. Rat. Mech. Anal.* **1**, 1952, 125) and Rivlin (*J. Rat. Mech. Anal.* **4**, 1955, 681). That their work is of a highly complex mathematical nature does not absolve any would-be author from considering it, for their results are of fundamental importance in the subject. The general dynamics of any fluid system must be based on tensor equations of state. Nothing less will do.

The treatment of visco-elastic fluids is rather unsatisfying. Only once, and then on page 37, long after the topic has been developed, is it explicitly stated that only the linear case is being considered. In other words only the 'Newtonian' approximation for fluids with a 'memory' is discussed. Much of the analytical discussion connecting creep functions and relaxation functions with generalized Maxwell or Voigt models is practically significant only for visco-elastic *solids* (i.e. materials for which the initial undeformed body geometry is crucially relevant throughout any experiment—and this is not in any sense an experiment into fluid behaviour). A further criticism is that many of the references are out of date, as a glance at the bibliography by anybody familiar with the literature will show. (For example the analysis of experimental data for visco-elastic systems in terms of linear Maxwell–Voigt models has been taken much further than the author suggests.)

The second chapter, on the experimental characterization of non-Newtonian fluids, provides a fairly comprehensive picture of the methods available for investigating non-Newtonian fluids. (The analytic definitions given in the first chapter are of just sufficient complexity to explain the type of behaviour quoted in the second.) There is, however, one curious lapse when the recovery curve in a creep-recovery experiment is stated to be a mirror image of the creep curve; this is never strictly true.

The third chapter, on the flow of non-Newtonian fluids in pipes and channels, is the most satisfactory of the book. It presents in a straightforward and elementary fashion those aspects of non-Newtonian flow that are relevant to pipe design. Friction factors and velocity profiles for steady laminar flow are given diagrammatically. The section on turbulent flow in pipes gives a good survey of recent work on the subject, in particular that of Metzner and co-workers. Here the author is evidently on familiar ground. The shorter sections on the extrusion of polymer melts and the rolling of plastics show less familiarity with the subject of polymer flow. The idealization chosen for flow in a single-screw extruder is an incorrect (and out-of-date) one in that it neglects the cross-flows (see, for example, *Industr. Engng Chem.* **51**, 1959, 765 and 841). Because of the critical effect of shear heating and of the shear and temperature-dependence of apparent viscosity, this error leads to major inaccuracies.

The following chapters, on heat-transfer and mixing characteristics, are a little sketchy but this only reflects the lack of good theoretical or experimental work on the subject. The final chapter is on viscometric measurements and apparatus.

A general impression given by parts of this book is of a lot of slightly undigested material being rather uncritically reported. This is a pity because it detracts from the merit of the more carefully written parts. The need for text-books on all the varied aspects of non-Newtonian flow has been felt for so long that any author attempting to fill the gaps is to be congratulated. Dr Wilkinson may not have produced a classical text on the mechanics of non-Newtonian fluids, but he has produced a book that should serve quite well as an introduction to the subject for students of engineering or chemical engineering. It is, moreover, pleasingly free from typographical errors.

J. R. A. PEARSON

Heat Transfer. By Alan J. Chapman. The Macmillan Company, New York. 1960. 452 pp. 63*s*.

In the last few years many textbooks have been published which, like the one reviewed here, present the elements of heat transfer to senior undergraduate and first-year graduate students of engineering. One of the earliest, that by Eckert, has been widely imitated, both on content and in manner of treatment; the present book conforms to the same type. This reviewer greeted Eckert's book enthusiastically, and has welcomed, though with diminishing fervour, its emulators. Surfeit has, however, now produced its accustomed effect, and the reviewer proposes, with apologies to Professor Chapman for using his book as the occasion, to begin the review with some remarks which apply more or less to the whole class of books referred to.

The subject is presented as consisting of three sections: conduction, convection and radiation. On a superficial view it might seem that a review for the *Journal of Fluid Mechanics* could be restricted to the second of these. While pondering whether to make this restriction, the reviewer hit on one of the reasons for his growing dissatisfaction with the conventional treatment. It is that the books in question either obscure, or at least fail to exploit, the close relations which exist between the theory of heat conduction and the theory of momentum and heat transfer in the fluid-mechanical boundary layer.

These relations derive of course from similarities in the governing differential equations, which are parabolic, linear in some cases, non-linear in others, and are as follows.

For one-dimensional transient heat conduction with a uniformly distributed heat source

$$c\rho\frac{\partial T}{\partial t} = \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + Q. \tag{1}$$

For the development of the steady two-dimensional velocity boundary layer

$$\rho u\frac{\partial u}{\partial x} = \rho u\frac{\partial}{\partial \Psi}\left(\mu\rho u\frac{\partial u}{\partial \Psi}\right) - \frac{dp}{dx}. \tag{2}$$

For the development of the steady two-dimensional thermal boundary layer with a uniformly distributed heat source

$$c\rho u\frac{\partial T}{\partial x} = \rho u\frac{\partial}{\partial \Psi}\left(k\rho u\frac{\partial T}{\partial \Psi}\right) + Q. \tag{3}$$

Q is the strength of the heat source, Ψ is the stream function and the other notation is conventional.

The similarity between the equations has often been noted. Why then are the solutions to equation (1) not used as stepping-stones to those of equations (2) and (3)? To see how this might be done, let us consider the simple case in which the heat-source and pressure-gradient terms are absent.

Equation (1), with boundary conditions appropriate to a semi-infinite medium with fixed wall temperature T_w, has the solution

$$\frac{T - T_w}{T_\infty - T_w} = f\left(\frac{y}{2\sqrt{(k_\infty t/c\rho)}}\right). \tag{4}$$

The function f involves the error function if k is a constant; when k depends on temperature, however, the function must normally be determined numerically. This much usually appears in the conduction section of the textbook.

Since equation (2), without the dp/dx term, has the same form, the student can now easily be led to appreciate that its solution must be

$$\frac{u}{u_\infty}=f\left(\frac{\psi}{2\sqrt{(\mu\rho u_\infty x)}}\right), \tag{5}$$

where now, due to the non-linearity of the right-hand side of the differential equation, numerical evaluation is *essential*. There is nothing else new in the situation whatsoever.

Equation (3) likewise has the solution

$$\frac{T-T_w}{T_\infty-T_w}=f\left(\frac{\psi}{2\sqrt{(k_\infty\rho u_\infty x/c)}}\right). \tag{6}$$

If the conductivity is independent of temperature, and the velocity can be taken as uniform through the thermal boundary layer as is the case for fluids of low Prandtl number, f is again the complementary error function; the student has obtained his first solution to a convective heat transfer problem at no extra trouble.

Of the many further relations which can be developed between conduction and convection it should suffice to mention two. First, in conduction theory, Duhamel's theorem is usually presented, permitting equation (4) to be used (for constant conductivity) for the evaluation of the temperature distribution and heat transfer rate when the wall temperature varies with *time*. Discussion of this theorem can pave the way for a presentation of methods, such as those of Tribus and Klein, for the calculation of convective heat transfer when the wall temperature varies with *position*. Secondly, when the conducting medium is finite in extent, textbooks on conduction show how the temperature distribution can be expressed as the sum of an infinite series of eigenfunctions. In simple cases these are sines and cosines. The same is true of heat transfer into a fluid confined in a duct, the sole difference being that there, because of the non-uniform velocity distribution, the eigenfunctions do not usually have such a simple form.

Once these relations and possibilities have been recognized, books such as that under review can be irritating. The author presents only the eigenfunction type of solution for the heat conduction equation; for convective heat transfer he presents only solutions like that of equation (6). Again, for convection he introduces approximate methods of the so-called 'integral' type, and readers who suspect that the same techniques might be valuable in conduction problems are given no encouragement. Dimensional analysis is introduced towards the end of the section on convection by way of illustrations drawn from elementary mechanics; the dimensionless groups which have cropped up on almost every page of the conduction chapters are not even mentioned in this connexion.

From this point of view therefore the book must be regarded as unimaginative; the author has kept closely to the paths trodden by his predecessors without looking to right or left. Within these limitations, however, he has done a careful and painstaking job. For example, his derivation of the equations of motion of the boundary layer is more rigorous than in most works of this character; and many of the detailed infelicities of earlier authors are avoided. Minor blemishes remain; for example, figure 6.10(*c*) illustrates a boundary layer on a cylinder having zero thickness at the forward stagnation line, and on page 261 the author recommends, without comment, formulae for the local Nusselt number on cones which contain no mention of the cone angle.

In conclusion, the reviewer would like to suggest to publishers that the market for the present class of book is now saturated. What seem to be required in future are, on the one hand books which unify and so simplify the whole field of heat transfer, and on the other books which select one aspect of the subject and treat it much more thoroughly than has been attempted hitherto.

D. B. SPALDING

Turbulence. An Introduction to Its Mechanism and Theory. By J. O. HINZE. New York: McGraw-Hill, 1959. 586 pp. $15.00 or £5. 16*s*. 6*d*.

A book on turbulence written for the beginner and also for many others who have their primary interest in the applications has been long awaited. The two excellent Cambridge Monographs (Batchelor 1953 and Townsend 1956) do not serve this purpose, since both were written more for an audience already familiar with the field and interested more in the inner workings of turbulence than in its gross effects on the mean values of the flow parameters.

Professor Hinze's book fills this demand largely, although not quite completely. The book is, of course, much longer than either of the above two monographs and the topics are handled with more attention to detail and to intermediate steps so it is easier reading for those who encounter the subject for the first time. It has certain value as a text-book, especially if used in a course on fluid mechanics for chemical engineers.

The author explains in the introduction that the book grew out of a lecture series given by him at the Royal Dutch Shell Laboratory in 1950. Most of the features of the book that may be criticized are a direct consequence of its origin. First, there is a great emphasis on phenomena important to chemical engineering; secondly, much more space is dedicated to the 'state of the art' as it was known before 1950 than to the later developments since that time.

The problem of turbulence in a compressible medium is almost completely ignored throughout. (There are some short remarks about 'effects of compressibility' but apparently these have been added only as an afterthought.) At one place (p. 131), the strange notion is proposed that turbulent density fluctuations in a compressible flow are uniquely related to the fluctuations of the velocity component in the mean flow direction and this is obviously wrong.

The reviewer also regrets that a vast array of applications in fields other than chemical engineering have not been included. More than anything else, this omission limits the usefulness of the book to serve as the principal text in a course on turbulence given for a group of graduate students as yet uncommitted to a more narrow field of specialization. Such a book is still awaited by those who have an active interest in teaching turbulence, both in theory and in applications. The interaction of turbulence with sound and some astrophysical or meteorological applications would have added much to the breadth of the book.

On the credit side, it must be acknowledged that the treatments of those topics that the author has decided to include are quite clear and skilful. The book is non-partisan in the sense that Professor Hinze does not attempt to force some personal bias on the reader, and he does not attempt to promote his own favoured theories or interpretations. The chapters are distinct, some of them almost monographs in themselves, and each one merits a short separate account.

I. General introduction and concepts (69 pages). It introduces the statistical concepts such as correlation function, one-dimensional spectrum, and deals clearly with the difference between Lagrangian and Eulerian representations. It is well presented and easy to read even by the uninitiated.

II. Measurement of turbulent flows (68 pages). The author here gives a survey dealing mostly with the hot-wire anemometer. It is intended to familiarize the reader with the problem of turbulence measurement, but it does not serve as a text for the design of equipment or even for the performance of experiments with existing equipment without further study of other sources. The electronic circuitry is not treated at all and the measurements are concerned only with low-speed flows (both incompressible and slightly heated).

III. Isotropic turbulence (103 pages). This is a good, well-detailed account of this classical subject, and for the beginner it may be even easier reading than Batchelor's 1953 monograph.

IV. Non-isotropic turbulence (22 pages). This short chapter deals with homogeneous shear flow and its significance is minor.

V. Transport processes: turbulent flows (100 pages). This chapter in a way provides the *raison d'être* of the book. The material collected here is quite valuable as it is hard to find it elsewhere except scattered in the original publications. Naturally, often the treatment is still based on mixing-length concepts and there are many crude engineering approximations. It may be safely predicted, however, that it will become one of the sources quoted most often in the chemical engineering community as far as turbulence is concerned.

VI. Non-isotropic free turbulence (70 pages). VII. Non-isotropic wall turbulence (70 pages). Both of these chapters deal with shear flow turbulence. Although the flow configurations are largely identical with those treated in Townsend's 1956 book, the approach is quite different. Professor Hinze emphasizes the prediction of the effect of turbulence on mean qualities (diffusion and shear) and not as much the inner workings of the turbulent flow itself. Chapter VI deals with wakes and jets; chapter VII deals with boundary layers (with no pressure gradient) and turbulent pipe flow. From the point of view of applications to aerodynamics it would have been extremely useful to include the treatment of the turbulent boundary layer with a pressure gradient.

There is an appendix on Cartesian tensors and it is quite useful.

Probably the most important function of a book review is to allow the prospective reader to judge whether or not he should acquire the book. For those who use fluid mechanics in an applied field and want to learn something about turbulence, the book is quite valuable especially for those with chemical engineering leanings. For the student of turbulence it is quite useful as a reference on many applications. Professor Hinze has been quite successful in introducing turbulence to a new and growing group of engineering students.

L. S. G. KOVASZNAY