REVIEWS

Momentum Transfer in Fluids, by W. H. CORCORAN, J. B. OPFELL and B. H. SAGE. New York: Academic Press Inc., 1956. 394 pp. 72*s*. or $9.00.

Towards the end of his monumental work on *Hydrodynamics*, Lamb says, " it remains only to call attention to the chief outstanding difficulty of our subject ", and goes on to explain that he is referring to turbulence. That sentence appeared first in the 1895 edition, and it has remained in all subsequent editions. Having called attention to the " difficulty ", Lamb let the matter rest there and said very little more. Lamb was fortunate, of course, in that he had a good story to tell about numerous other parts of the subject, and nobody minds the omission. Other, later, writers of textbooks on fluid mechanics for the student or the practising engineer are not so well placed, and are obliged to do more than " call attention to the difficulty ". Some help must be provided to the aeronautical engineer who wishes to calculate skin friction, to the meteorologist who wishes to predict atmospheric diffusion rates, and to the chemical engineer who wishes to relate mass transfer in a model experiment to that in a full-scale plant. Modern technology needs help in describing and analysing turbulent flow, and cannot wait for scientists to understand its mysteries. Nor is it sufficient to provide a collection of data in the style of a handbook, since the variety of types and effects of turbulent flows is too large to allow cataloguing. Some kind of rational analysis of turbulence is demanded, in such a form that the student or engineer can apply it with understanding and confidence in many different situations.

Faced with this need, the modern writer of a textbook on turbulent flows of one kind or another can proceed in either of two different ways. The first way, which has been commonly adopted, is to present the older analysis usually described as ' mixing-length theory '. This analysis serves quite well as a framework for an empirical description of turbulent motion, but as a *theory* it has lost vitality and has been at a standstill for 20 years. It seemed at one stage to have considerable promise, since it was able to provide reasonably accurate predictions of mean velocity profiles in wakes, jets, mixing regions, and other cases of nearly unidirectional mean flows, with only a small number of assumptions; however, later work suggested that this was due in large measure to the insensitivity of the profiles to the assumptions used, and that, as a consequence of the strong geometrical restrictions on the possible form of the profile in such cases, almost any theory can achieve some success. The engineer is especially interested in transfer rates, and here ' mixing-length theory ' is much less successful in its predictions; in this sphere it has value only as a language for the description of what has already been measured.

It is all to easy to adopt a superior attitude to the old ideas of transfer of momentum, vorticity and heat by a mixing process. They have been fair game for attack by many of us for a number of years, but no one has had much success in producing an alternative line. In 1950 Schlichting wrote, in the preface of his book *Grenzsch icht-Theorie,* " It is true that according to present views these theories possess a number of shortcomings but nothing superior has so far been devised to take their place, nothing that is, which is useful to the engineer. ... statistical theories of turbulence have not attained any practical significance for engineers ". I do not think the second part of this quotation was valid in 1950, and I am sure it is not valid now; however, there will be general agreement with the first part, and therein lies the rub. The modern or so-called statistical theories of turbulence (not entirely an appropriate description since there is no particular *theory* or set of assumptions or hypotheses underlying the modern work; it is characterized by nothing more than a recognition of the random character of turbulent velocity fluctuations and of the necessity to describe turbulence statistically) have not yet fulfilled the promise they were believed to have. The first aims of the ' statistical theory ', to develop a mathematical framework for the description of a random three-dimensional continuous velocity field, and to use the equations of motion and of continuity to obtain relations between different elements of this description, have been achieved, and many people believe that this prepares the way for the development of theories that will yield useful results for the engineer. So far, that has not happened to any appreciable extent, although recent advances in understanding of the mechanism of turbulence, as described by Townsend in his book *The Structure of Turbulent Shear Flow,* give renewed hope that the engineer will not have to wait very much longer. There is of course no going back on the ' statistical theory ', whatever its lack of success in hard practical terms, since in essence it is only a descriptive framework, whose use is just as inevitable in turbulence as it is in any other subject involving random quantities, such as molecular motion in gases.

The second possible course open to the writer of a textbook about turbulent flow is to grasp the nettle firmly, to do the best he can with modern ' statistical theory ' and to refuse the doubtful help of discredited or unreliable theories. This course has not yet been pursued wholeheartedly in a textbook, and we cannot readily judge whether it would be successful in meeting the needs of engineers. It may not be quite as difficult as at first it seems. By making the widest possible use of dimensional analysis (which reproduces many of the intermediate results of the mixing-length theories), and by introducing inferences from previous measurements in very general form, particularly those concerning firstly the region of nearly uniform stress near a rigid wall and secondly the region of a turbulent flow that is *not* affected directly by the presence of a rigid wall (the ' law of the wall ' and the ' law of the wake ', discussed recently by Coles in this journal, are examples of such empirical generalizations), all this being done within the framework provided by the ' statistical theory ' and interpreted in the light of the now considerable body of knowledge about the mechanics of turbulence, it might be possible to produce a satisfactory textbook book about turbulence. It is certainly worth trying, in view of the potential value of such a book.

The book under notice is by three chemical engineers at California Institute of Technology and, according to the preface, is intended to describe a part of fluid mechanics that is " of special interest to chemical engineers ". They take this to include the fundamentals of viscous fluid flow, boundary layers, and turbulence, with emphasis on cases of flow through pipes and channels. That three teachers of chemical engineering should feel impelled to write a textbook, mostly about turbulent flow, for use by advanced students and practicing engineers, suggests that the writings of turbulence specialists have not been found very helpful. Such a venture would seem to demand courage, but in fact a reading of the book suggests that it is the courage of the blind who do not know what pitfalls lie about them. At a brisk pace they cover a wide range of topics of alarmingly different degrees of difficulty, and spend little or no time on discussion of the pros and cons of different ideas. When an hypothesis is introduced, the responsibility is pushed back on its originator; von Kármán said this, Prandtl said that, this is Schlichting's result, that is Pohlhausen's, and so on. This is the handbook manner, which is very useful in its place, but which leads here to a disturbing lack of discrimination in the selection and presentation of the available information about turbulence.

The authors seem to have been uneasily aware of the above two possible points of view about a textbook treatment of turbulence, and their answer is to use both. Not in the same chapter, for that is scarcely possible, but in different parts of the book. Of the five large sections on turbulent flow (four chapters and an appendix), three are substantially about the pre-war theories and types of measurement, and say little that is not in *Modern Developments in Fluid Dynamics* (1938) or Bakhmeteff's book, *The Mechanics of Turbulent Flow* (1941); the other two use the language and notions of the ' modern approach ' to turbulent flow. These two divisions of the book are not integrated, or even related, and one suspects that the authors were playing for safety; if the reader wants the simple relations and analysis provided by transport theories, the book provides that, and, if tomorrow's research should suddenly make statistical theories useful, all the reader has to do is to jump a chapter or two. Of the two divisions, that concerned with the ' modern approach ' is the less satisfactory. The authors evidently have great respect for the complicated game played with tensors by theoreticians, and their deference has led them to include a large appendix containing long derivations of formulae (for example, for triple correlations in isotropic turbulence) of which they make no use and about which they make no comment. This is no more than a genuflexion before the altar of ' high-brow ' analysis, and the book would be both more honest and less confusing without it. The chapter on the ' modern approach ' to turbulence is similarly characterized by enthusiasm rather than care, and by an absence of any comment which would help a reader to judge the value of the different concepts and ideas. Even the experimental data reproduced here is of doubtful value, since the quantities concerned, such as the kinetic energy spectrum, are not explained adequately. No; so far as current ideas about turbulence are concerned, this book is not likely to help the student or engineer; it is unlikely either to make available to him the small stock of practically useful results or to give him an understanding of what the current ideas are about.

Such contribution as the book does make, and it cannot be reckoned as large, is to gather together the data about flow in pipes, channels and boundary layers, including the effects of wall roughness and wall heating, and to present this in the way that has been familiar to aeronautical and mechanical engineers during the past 25 years. A book with this aim might well be very useful, since most of the existing accounts, such as *Modern Developments in Fluid Dynamics*, perhaps give more discussion than is useful to a person who wishes only to know what data is available and when it is applicable. I think that this was what the authors set out to do, but I cannot feel that they have succeeded. They seem to have paid little attention to the *plan* of their work or to the need for systematic presentation of material. Chapters 2, 3 and 6 are entitled " Some simple properties of turbulent flow ", " Some macroscopic characteristics of turbulent flow ", and " Some properties of turbulence " ; how can anyone find his way about a book that provides such vague directions ? Within each chapter the arrangement of sections has little perceptible order or of the gradual development of a theme. The vorticity transfer hypothesis is introduced and, in order to put the reader in the picture, the definition of vorticity has to be provided in a footnote; the no-slip condition at a rigid wall is given in the section entitled " Boundary conditions for the equation of continuity "; a section entitled " Measurement of the physical nature of turbulence " (whatever that may mean) begins with talk about velocity fluctuations and then for no apparent reason proceeds to devote most of its length to a discussion of the width of the mean temperature profile behind a hot body in a turbulent stream; and many other examples of an almost random arrangement of material could be given. The authors had the advantage of writing in 1956, with many more published papers to call on for help, but even so I doubt if their book is clearer and more informative than the many older accounts of the subject.

The book is also marred by slipshod writing. Non sequiturs, clumsy constructions, ill-chosen words, and even grammatical errors, are numerous in all parts of the book. We are accustomed nowadays to an unadorned, rather blank, arid, style of writing in scientific books, and for some reason books for engineers seem to have gone farthest in this direction, but surely readers may still expect a certain minimum standard of care and respect for the rules of composition. To reach this standard does not require literary skill and practice; it requires only that one should be willing to take time and trouble, and in particular to go over one's work several times. Is it conceivable that each of the three authors read and approved of the sentence (p. 114) " The restriction homogeneous is used so that the equations to be developed are mathematically correct inasmuch as the analyses will be confined to regions where all functions of interest are continuous and differentiable " ? One sees what the authors mean in cases where precision of thought is not needed, but there are places where their sloppy writing definitely impedes understanding. I can only guess the meanings of " The intensive properties of the fluid will be considered to be independent of state " (p. 11), of the symbol j defined as " Friction per unit time in differential length of total conduit, ft. lb./sec." (p. 44), and of " Steady laminar boundary layers are actually of infinite thickness but it is convenient to consider finite thicknesses of the boundary layer for purposes of practical calculations " (p. 240). The effect on a measuring instrument of its velocity relative to the fluid is described as if it were a property of the coordinate system (p. 7), boundary layer separation is entangled with stability (p. 265), and § VII–9 is a thorough muddle of the two cases of a time-dependent laminar boundary layer on an infinite flat plate and of a steady boundary layer on a semi-infinite flat plate. Many other examples could be given, and remarks in similar vein could be made about the clumsiness of the more mathematical arguments. This is ' first-draft ' writing and it is sheer irresponsibility to put it into print.

It is of course always possible to learn something from a new book. I myself picked up one little wrinkle, which I have stored away mentally for use on occasions when I wish to impress students with my progressive outlook; it is that when one is establishing the equation of continuity, it is nowadays desirable to exclude the possibility that nuclear reactions are going on in the volume element under consideration.

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