REVIEWS

Handbook of Fluid Dynamics. Edited by V. L. STREETER. McGraw-Hill, 1961. 1215 pp. £9. 6*s*.

This handbook is intended to cover the main fundamental and applied aspects of fluid dynamics that are important in engineering. Each of the 27 chapters is separately written (by one or more of the 31 contributors) and can be read independently. The first ten chapters are concerned with the classical formulation of fluid dynamics: e.g. the basic equations, ideal fluid flow, laminar flow, boundary-layer theory, compressible flow and turbulence. The later chapters represent various stages of application: some are fairly general, like flow through porous media, separation, cavitation, sedimentation, lubrication, two-phase flow, open-channel flow or stratified flow; some are more specialized, like turbomachinery, transmission of power and jet propulsion. There are a few topics difficult to classify like dimensional analysis, flow measurement, magnetohydrodynamics and digital computation.

Although the book is very long, the text running to over 1200 pages, each chapter gives the impression of great compression; this is because a very wide field of knowledge is covered and a very large number of results are presented. Because of this encyclopaedic tendency, the book has little didactic merit and will not be of great use to the specialist. It must be regarded therefore as a reference book (it has a necessarily ample index) to be used when the reader has neither the time to master a particular subject in detail nor the opportunity to cover all the relevant references.

Once having accepted its purpose, this book has many merits. Most of its authors are well known and expert in their separate fields. It is, for most of its topics, up-to-date and provides a very useful set of references well introduced by the text. Some of the authors (e.g. A. H. Shapiro on the 'Basic equations of fluid flow', A. B. Metzner on the 'Flow of non-Newtonian fluids' and R. C. Dean on 'Separation and stall', to mention a few) have produced chapters that rise above the rather flat accounts that must be expected in most cases and are interesting to read in themelves; equally, some (e.g. C.-S. Yih on 'Ideal fluid flow and S. I. Pai on 'Laminar flow') have provided rather indigestible accounts that really have no bearing on the basic engineering outlook of the book. In general, it is the more practical accounts that will be most welcome, particularly for the theoretically trained engineer who needs a short survey of available results in a subject that is new to him. On the whole, the chapters represent exhaustive rather than critical accounts of these results.

For a reader familiar with the subject-matter of any chapter, the book could be a useful source for the exact details of equations, constants and analytical or numerical results (the book is very generously provided with results displayed in graphical form). It contains, unfortunately, rather many printer's errors that should have been eliminated at the proof stage, and is printed in type inconveniently small for reading; it is otherwise well produced and bound in the best American style, a point very much in its favour if used for reference purposes.

Although the chapters cover a wide range of fundamental and applied topics, there are a few notable omissions from the field of learning conventionally associated with fluid dynamics: high-speed aerodynamics, wave motion and instability theory are conspicuously absent. The neglect of the latter two topics throughout the book is perhaps its principal demerit: it is arguable that the *undesirable* appearance of secondary flows and periodic disturbances in fluid systems is one of the principal problems of engineering fluid mechanics. The breakdown of laminar to turbulent flow is, of course, included in this text, and passing reference is made elsewhere to other cases of flow breakdown. But no emphasis is placed on the unfortunate fact that designing a device to provide the right flow pattern in assumed steady-flow conditions provides no guarantee that such steady-flow conditions will be achieved in practice. To quote from two other fields of engineering, the ill-founded optimism underlying the early work on controlled thermonuclear reactions or the fate of the Tacoma bridge should underline the danger of neglecting instability effects.

J. R. A. PEARSON

Introduction Mathématique à la Mécanique des Fluides. By CAIUS JACOB. (In French.) Paris: Gauthier Villars, 1959. 1286 pp. 45 NF or $10.00.

The general structure, contents and spirit of this important work can be summarized as follows: Prof. Caius Jacob treats both incompressible and compressible fluids at approximately equal length (about 500 pages each); these divisions are preceded by an extensive presentation of the theory of harmonic functions of two variables; the book in general is centred on the ideal fluid and on the exact and general solution of the problems treated; these problems are concerned principally with the forces on moving bodies, in other words the sector of fluid mechanics influenced by aeronautical applications.

Departing somewhat from the headings adopted by the author, the eight chapters dealing with incompressible fluid can be grouped under four main headings: (1) general aspects of three-dimensional flows (165 pages), (2) two-dimensional flows (152 pages), (3) Helmholtz wakes and Kirchhoff jets (88 pages), (4) aerofoil theory (95 pages). The reviewer considers that the title 'Resistance theories' under which are grouped sections 3 and 4 is not the best way to characterize the interest of jets and wakes and is otherwise incomplete without referring to boundary layers, turbulence, vortex sheets, etc.

The study of the general principles includes the derivation of the fundamental equations for ideal as well as for viscous flows. The latter, especially in the section concerning the energy equation and the thermal aspects, are in the reviewer's opinion dealt with too briefly, particularly in view of the later development of compressible flows. The d'Alembert paradox is discussed at length, but here one would like to have seen treated some of the interesting problems of virtual mass. The calculation of velocities from the vorticity distribution is a clear and excellent synthesis of the classical solutions and of recent progress in the subject.

The general problems considered under the heading of two-dimensional flows include the fixed obstacle in a moving fluid, and the moving body in a fluid at rest, and flows with given singularities. Particular problems treated are the rotating plate and paddle wheel (but does the theoretical description without separation adequately represent the facts?) and the disturbance due to an obstacle placed above a flat surface in a flow with constant velocity gradient.

The chapters relative to wakes and jets give a lucid description of a problem which has interested hydrodynamicists for over a century, and the reader will appreciate the author's presentation of the classical formulation of the problem by Levi-Civita and Villat, the solution for the case of a symmetrical body by means of two intergal equations, and the detailed discussion of the case of the circular arc body. Next are treated in detail an incident liquid stream which is itself limited by free streamlines, and the case of jets issuing from a container (where the theory is closest to reality).

The division of the book devoted to incompressible fluids is concluded by two chapters on aerofoil theory and wings of infinite and finite aspect ratio. The two-dimensional problems include the thin aerofoil approximation (by two methods), the wing with a vortex sheet at the trailing edge resulting from a non-uniform motion, the wing with a highly idealized jet, and finally cascades. The case of the finite span includes the well-known Prandtl model, and a discussion of some recent methods of obtaining exact solutions of the resultant integral differential equation. In conclusion the author investigates the disturbance to the flow field around a finite wing due to the wall of a circular tunnel.

The study of compressible fluids occupies the second division of Prof. Jacob's book and it would perhaps have been useful in view of its length to have made it into a separate volume. In eight chapters, the author presents firstly fundamental principles and exact theoretical solutions, and secondly the numerous methods of approximation used in subsonic and supersonic flow (with a final incursion into the transonic domain).

The treatment of fundamentals (75 pages) includes the general theory of wave propagation, the properties of second-order partial differential equations, and the basic equation for compressible flow. It should be noted that a given relation between specific mass and pressure is postulated at the beginning (in other words homentropic or isothermal flow) and that potential flow is assumed throughout.

The presentation of rigorous solutions for the subsonic régime (steady two-dimensional flows) is centred on the hodograph variables and Chaplygin's corresponding equation. The 120 pages devoted to this remarkable achievement of the theory constitute one of the major chapters of the book. From Chaplygin's solutions Prof. Jacob has deduced a complete solution for the problem of subsonic jets, generalizing that for incompressible flow and the calculation of the contraction coefficient with close upper and lower bounds. The author also considers the problem of a stream impinging on a flat plate or wedge, and gives methods of calculation of the functions involved.

In the supersonic régime the exact solutions examined are those in which simple waves appear—flow round a corner, flat aerofoils, polygonal and biconvex profiles—with of course the shock wave taken into account when it arises. The chapter (48 pages) concludes with a study of axially symmetric conical flows.

Methods of approximation in subsonic flows (154 pages) begin with an examination of several procedures which use the physical plane. An example is the procedure combining the potential and stream functions, as a function of the variable z (physical plane) and its conjugate. Prof. Jacob has applied it brilliantly to the study of jets in compressible flows, and has deduced a very simple relation which gives a good approximation to the contraction coefficient. Here again it is the methods of approximation based on the hodograph plane which occupy the major part of the section. He gives a method which recalls the preceding one in the actual variables and is particularly economic for the study of free streamlines. Especially noteworthy is the remarkable correspondance between the incompressible and the Chaplygin fluid. The reader will find applications of this method to the study of circular and elliptic obstacles and to wake and jet problems, together with the necessary modification for flows with circulation.

In the final section on supersonic flows, the approximation used is essentially the linearized theory. The author recalls briefly the classical simplification in the use of characteristics for two-dimensional flows and concentrates on the elegant conical flow theory. Included in this chapter (105 pages) are the applications to the oblate cone and angular plate, an extension to the case of supersonic edges, and finally the use of the solutions obtained for the study of rectangular and trapezoidal wings.

As noted previously, the book begins with an extensive mathematical introduction, in which are treated the general methods applicable to harmonic boundary-value problems. These problems, which form the backbone of the book, consist for an harmonic function in the familiar conditions for the function or its normal derivative at the boundary, and for an holomorphic function in given values of either the real or the imaginary part or of a linear combination of both. The first two chapters of this division (104 pages) contain a clear exposition of what should be known about circular and then non-circular domains. The reviewer particularly noted the third chapter (118) pages) where these problems are reduced to the solution of integral equation of the Fredholm type. Throughout these are difficult problems to which the author has made personal contributions.

The reader to whom the task of reviewing this book has fallen is nearer to physics than pure mathematics, and his impressions are summarized in conclusion from this standpoint. The depth and range of information contained in the book is completed by a bibliography (with many French and Russian references) judiciously included in each chapter in the form of historical notes. The presentation begins always from first principles and is developed in a very explicit manner (the reader has rarely to fill in intermediate steps), and even the more difficult aspects give a remarkable impression of clarity. Throughout the book there is unity of method and style, due to the extensive personal contribution made by the author to most of the subjects dealt with, but most of all due to the mathematical methods which have determined the choice of the problems and make for their resemblance. In the reviewer's opinion the book is an excellent self-contained working instrument, to which the reader will turn to with confidence. As always however, everything cannot be expected from it. The book treats only one sector of fluid mechanics, which although important covers neither the whole of the classical domain, nor of course the new developments in the physics of fluids which have brought new freshness to the field. Physical theories comprise several stages, from the discovery of new facts, through the development of a theoretical model and its justification, to the discovery of analytical and numerical methods of solution; obviously Prof. Jacob's book is concerned principally with the last stage.

A. CRAYA

La Mécanique des Fluides et la Magnétohydrodynamique. Paris: Eyrolles, 1962. 168 pp. 25.00 NF.

This little volume contains the communications presented at a one-day meeting of the French *Société Hydrotechnique* held on 17 March 1961 and devoted to a survey of applied magnetohydrodynamics. Most of the speakers were engineers although a leavening of applied mathematicians was present.

The proceedings opened with a vigorous review of the subject's history and scope by Gibrat. This was selective rather than exhaustive. Gibrat went on to remind his audience of the Kantrowitz–Petscheck classification of régimes in plasmas on a basis of electron density and temperature.

There followed three papers classed together as general theory, but in fact more unified by their common inspiration from controlled fusion research. Palumbo gave a useful review of the usual themes such as the fluid-particle duality and the need to allow for anisotropic pressure in collision-free plasmas. His main theme was confinement of static plasma by magnetic fields; but he contrived to mention many other ideas, well known but important. The next paper by Mercier took the story further with a more detailed discussion of magnetohydrostatic confinement and the study of its stability by the standard energy principles. Colombo terminated this part of the meeting with a discourse on relativistic magnetohydrodynamics which, rather surprisingly, stimulated more discussion than any other paper. The discussions are reported at the end of the book.

The second group of three papers were classed as theory of particular flows and proved to be about duct or pipe flows. Mesrine was concerned with the question of justifying the one-dimensional approach to compressible, conducting flows in ducts and the problems of allowing for different mean velocities in statements of the conservation of mass, momentum and energy. Caseau developed an obscure, if original, analysis of two-dimensional flows in ducts at low magnetic Reynolds number. It is hard to comprehend his notation, possibly because of the many misprints which occur throughout the book. Finally Engeldinger gave a worthwhile and comprehensive survey of present knowledge on incompressible flows in pipes under mostly transverse fields. One can only heartily endorse his plea for more experiments on turbulence and instability in pipe flow.

The last pair of papers were devoted to the possibility of direct generation of electricity from hot gas streams moving through transverse magnetic fields. Both papers tended to cover the same material, rather cursorily, and did not appear to add to the knowledge already available elsewhere. Klein did mention devices already in use such as electromagnetic pumps, while Fabre and Péricart presented more interesting facts, data on refractory materials and graphs of the behaviour of magnetohydrodynamic generators according to one-dimensional theory at constant area or Mach number. They exploited their opportunity to have the last word at the meeting—apart from the discussion—with the imaginative suggestion that useful magnetohydrodynamic devices still remain to be discovered which can fully exploit the unlimited deformability of the moving conductor, not available to the orthodox machine designer.

This is obviously not an indispensable book since it presents little that is not already widely circulated. However, it does compress into a small compass a lot of the important ideas that are current in applied magnetohydrodynamics and French readers in particular will find it a useful compilation.

J. A. SHERCLIFF

Ludwig Prandtl: Gesammelte Abhandlungen zur angewandten Mechanik, Hydro und Aerodynamik. Edited by W. TOLLMIEN, H. SCHLICHTING, H. GÖRTLER and F. W. RIEGELS. Springer-Verlag, 1961. 1620 pp. in 3 vols. DM. 273, paper covers; DM. 288, linen.

During a long period extending over roughly the entire first half of the twentieth century, Prof. Ludwig Prandtl of Göttingen was known not only as an outstanding teacher and scientist of fluid mechanics, but also in a way as an 'institution'. He successfully combined the role of the theoretician, experimentalist, teacher, and leader, and one often hears from those who knew him in person that he was a witty person and a warm human being.

Now his collected papers have been published, and when one glances through the three volumes (with more than 1600 pages of text) it is clear that a conventional book review is out of the question. One must try instead to reassess Prandtl's impact on the development of fluid mechanics during his active lifetime and his place in the rapid growth of the field in the first half of our century.

It is quite fascinating to follow the turns and twists of such a great mind as he has explored certain main and recurring themes and also as he has tried to exploit the many ramifications into a host of secondary and somewhat more applied problems.

At the end of the third volume, doctoral theses prepared under Prandtl are listed and the 81 names, many of them quite illustrious, provide a good measure of the influence he exerted over the field of applied mechanics. For most of the time he had with him young post-doctoral workers, and their joint work with Prandtl often earned them early recognition.

The most fascinating aspect of Prandtl's scientific personality was his remarkable talent to find 'short-cuts' by physical intuition, so as to render a problem mathematically tractable without actually sacrificing too much of the essential features of the phenomenon. At first this must have been an entirely intuitive and also a highly personal approach but he later tried to train his students and associates in this art; looking back, one has the impression that he had considerable success.

As one follows the shifts of his interest it is clear in retrospect that he has chosen problems that appeared hopelessly complex to others at the time but he could see a way to simplify them and still obtain physically meaningful results. It is quite conceivable that his intense and continuing interest in experimentation helped him to maintain an intimate contact with the physical world and was the source of his ability to simplify the problem on physical rather than on mathematical grounds.

Prandtl's own doctoral thesis was written on a problem in buckling; already it shows his keen interest in the actual physical phenomenon, as he was not merely treating a set of equations.

The use of analogue phenomena to enlighten another less understood one is commonplace nowadays, but during Prandtl's early career this was a rather novel device. He used analogies also to bring out dramatically the common underlying mathematical structure of several physical phenomena. It also helped him to borrow well-known results from another and better explored analogue phenomenon. He exploited the analogy between the stress distribution of prismatic bar in torison and the deflection of a soap film (1904).

Dimensional reasoning that has become now a staple commodity in fluid mechanics teaching owes much to Prandtl who was an early and ingenious practitioner himself. At the advent of aerodynamics he was one of the great proponents of proper nondimensional presentation of experimental results. The aerodynamic laboratory in Göttingen that he set up and directed was a great source of early aerodynamic data serving the budding aviation industry.

The reviewer shares the majority opinion that Prandtl's greatest single contribution to fluid mechanics was the formulation of the boundary-layer theory (1904). Although the concepts are well known to most fluid mechanicists, is still gives pleasure to reread the original text more than fifty years after it was written. Of course, Prandtl himself was often asked how he came to formulate it and what was his secret in working with such difficult problems. In his own account ('My path to hydrodynamic theories', 1948) he claims his first inspiration arose out of the frustration experienced when dealing with a practical engineering problem. As a very young engineer he designed some diffusers which must have had separated flow as they did not produce the expected pressure recovery. His thoughts wondered from flow separation to the shear layer itself that must exist adjacent to the wall, and after about three years of brooding and speculating the boundary-layer theory resulted. After he had arrived at the conclusion that the full Navier–Stokes equations are hopeless, he made his bold simplification based on consideration of the relative orders of magnitude among the different terms.

He relates how in working with a difficult problem he used the following recipe. First, reduce the complexity of the equation by judiciously choosing a coefficient zero. Then solve the simplified problem from which the troublesome term has been dropped. In the second step, restore the previously neglected term with a very small coefficient and solve the equation by an appropriate approximate method. Investigate now in what way the solution of this somewhat more complicated problem differs from the simplified one, and check in particular whether or not the limiting case of the vanishing parameter yields the same solution as when the parameter is actually zero. If the answer is to the affirmative the zero parameter solution is useful. He also described how he plotted solutions to a problem that he had only guessed and how by plotting also the different derivatives he could add up the terms in a differential equation and see which term contributes more and which one less. In this way he acquired an intimate 'feeling' for the phenomenon instead of using the more formal mathematical approach.

The effect of compressibility started to fascinate him at an early time (1904). He began investigating nozzle flow and after some success with small amplitude wave theory he made important contributions concerning stationary normal shock-waves. He complemented the theoretical considerations with revealing experiments. His best known contributions in the field of compressibility are both joint papers that are now regarded as classics. The first is the supersonic flow around a corner (Prandtl–Meyer 1908) and the second is the foundation of the method of characteristics for supersonic flows (Prandtl–Busemann 1929).

The analogy between heat transfer and viscous skin friction was originally proposed by O. Reynolds. After Prandtl had established the boundary-layer theory he started to delve further into this relationship (1910), and the non-dimensional parameter that characterizes the relative magnitude of the two diffusivities in a medium now bears his name.

One extension of his boundary-layer theory from skin friction to heat transfer was followed by another extension, namely from laminar to turbulent flow. Boussinesq first proposed to treat turbulent flows 'in the mean' in the same way as laminar ones except with new increased turbulent transport properties. Prandtl as first was mainly interested in almost parallel shear flows and he proposed a simple formulation that made the transport properties of the turbulent medium variable across the flow field and also dependent on the mean flow gradient (mixing-length theories).

Nevertheless, Prandtl's first interest in turbulence came not from such theoretical speculations but from an experimental observation. The sudden drop in the drag of a sphere (and the change of flow pattern) at a definite but high 'critical' Reynolds number is caused by the laminar-turbulence transition in the very thin boundary layer along the surface of the sphere and the attendant shift in the separation point. Furthermore, it was proven that this critical Reynolds number at which the rather spectacular change occurs is also strongly dependent on the turbulence level of the oncoming air stream (1914).

On the theoretical side, Prandtl and his pupils vigorously pursued extensive applications of the Prandtl mixing-length (Mischungsweg) approach and this had both some advantages and disadvantages for the overall development of fluid mechanics. On the positive side, they were able to supply solutions to turbulent shear flows predicting mean velocity distributions and heat transfer rates which were in good agreement with experiments; on the negative side, they probably have retarded the development of more penetrating turbulence theories in Germany in general and in Göttingen in particular. The philosophy that all macroscopic effects of turbulence (shear, heat-transfer, etc.) must depend entirely on the mean flow characteristics of course rendered the problem soluble but conveniently by-passed the issue as far as the nature of the random fluctuation fields were concerned. Of course, the experimental techniques that later permitted the measurements of the turbulent fluctuations themselves were in their infancy and the pragmatism had a certain justification. The very nature of the mixing-length theory must have discouraged the practitioners from looking at flows that have no mean velocity gradient, such as the decaying grid turbulence. Similarly, the concept of isotropic turbulence had no great appeal under such circumstances. The reviewer believes that exactly because of the easy, almost automatic, applicability of the mixing-length type of theory, turbulence research proper was delayed in Göttingen.

The demands of the growing aviation for aerodynamic testing led Prandtl to consider the reconciliation of two-dimensional airfoil theory with the three dimensionality of a finite span wing. Prandtl's finite wing theory (1918–19) exhibits the same simplicity as his other successful works. The chief contribution was the conceptual simplicity of the lifting-line approach and the rather simple formulation based on insight of what is negligible. Prandtl, in fact, had built this theory on the work of others (in this case Lanchester and Munk) but finally it was his simple formulation that had lasting usefulness.

Among the minor themes he was interested in, meteorological problems play a prominent role. He worked especially in the area where the rotation of the earth is important. He had a rotating laboratory in Göttingen used to explore effects of rotation. His last original publication offered an explanation for the planetary jet-stream (1950).

Prandtl as leader of a research group was responsible for the laboratory in Göttingen. A supersonic blown-down tunnel was operated at a rather early time and many studies in gasdynamics have originated there. A heat transfer tunnel was among his early interests. A measuring probe that combine a Pitot probe with a static one still bears his name.

It is no accident that he maintained such a continuing interest in experimentation; it supplied him with this intimate feeling of physical reality that he praised far above any mathematical elegance.

Even though much of the material is well known now and even may be found in text-books, one still derives much insight from reading Prandtl's original exposition.

L. S. G. Kovasznay