REVIEWS

History of Hydraulics, by HUNTER ROUSE and SIMON INCE. Iowa City: Iowa Institute of Hydraulic Research, State University of Iowa, 1957. 269 pp. $5.00.

In these days of high blood pressure and rapid advancement in science and technology, it is refreshing to find a book which halts the headlong rush and contemplates the past. Here is a harmless tranquiliser to which all those interested in fluid mechanics should become addicted. The historical development of hydraulics since early antiquity is briefly but expertly recounted in a way which enables the reader to see the progress of the subject in its proper perspective. The aim has been to review the advances made in formulating the basic principles of fluid motion, together with those relevant aspects of experimental research, engineering design, related scientific progress and world history. Hydraulicists will be aware that much of the material for the book has already been published as a series of supplements to *La Houille Blanche* which has regularly featured historical and biographical notes.

The distinguished senior author, who is prominent in the advancement of engineering fluid mechanics, has also, most fortunately, been interested in the historical and philosophical progress of his subject. In 1950 he therefore encouraged a research student at Iowa, Simon Ince, to prepare a thesis on " A history of hydraulics at the end of the 18th century " which was submitted in 1952. When, some years later as a Fulbright Scholar, Professor Rouse spent a year at the University of Grenoble, it was an excellent opportunity to expand the original thesis. He was greatly aided by the unrivalled library facilities which had been built up in the neighbouring Laboratoire Dauphinoise d'Hydraulique under the genius of another eminent hydraulicist, Pierre Danel. With such a fusion of backgrounds it is little wonder that the book flourished.

Inevitably, because water is such an important element in life, ' Hydraulics ' must be one of the oldest subjects studied by man. Initially, its study was presumably empirical, but later it proved a fruitful field for theoreticians. One of the fascinating aspects of the book is its revelation of the close link in the past between the mathematician, the scientist and the hydraulic engineer, who in the 18th century were usually one and the same person. Nowadays in this era of specialization the field has broadened into what is fashionably termed fluid mechanics and the pursuit divided between aero- and hydro-dynamicists, engineers, meteorologists and a host of others who sometimes delude themselves that their own subject is ' different '. It is, in fact, often difficult to see the wood for the trees, and for this reason the book is welcome because of the clear view that it presents.

The story begins in the days, difficult for historians, when ancient civilizations were developing the middle east. Little is recorded, but it is interesting, for instance, to note that the siphon dates at least from those times. The later periods of Greek and Roman culture are fortunately better documented in classical literature, from which numerous quotations are taken. The theoretical contributions to hydrostatics by Archimedes and the philosophy of Aristotle and others are famous but it may not always be appreciated that the Greeks were also competent hydraulic engineers, their skills as canal and tunnel builders probably being inherited from the middle east. On the mechanical side, Ctesibus is accredited with the first recorded positive displacement pump, and the steam-jet turbine described by Hero is well known. The Romans were outstanding as water handlers and have left behind many hydraulic structures as evidence of their engineering skill. Although illustrations from the middle ages depict the use of hydraulic machines in mills and forges, no outstanding figures in hydromechanics seem to have emerged. Examples are quoted of a few gropings towards mechanics made by Buridan of the University of Paris, Heytesbury of Oxford and others, but little is known of scientific progress during this period. In addition to the references quoted by Rouse and Ince the translated modern edition of *De Re Metallica* by Georgius Agricola might also have been mentioned as a valuable source of illustrations of hydraulic machinery used in mining during the middle ages. However, not until Leonardo da Vinci and the Renaissance do the individual contributions of hydraulicists become apparent. The drawings of hydraulic phenomena made by da Vinci and reproduced in the book show da Vinci's acute powers of observation, and extracts from his writings reveal a remarkable understanding of physical laws such as those of force and work. Others such as Copernicus, Stevin and Galileo also contributed to the progress of mechanics and the experimental method during this early period. From here on the story moves more rapidly through chapters on the naissance of the experimental method, post-renaissance hydraulics, 17th-century mathematics and mechanics, to the 18th century when theoretical hydrodynamics really began and remarkable advances were made. The 16th, 17th and 18th centuries may be the most fascinating periods for many readers, partly because they cover the birth and development of hydrodynamics as we know it and partly because we are less familiar with these times than with the more recent developments in the 19th and 20th centuries. The versatility of many of the scientists is remarkable. For instance, Newton is said to have discovered the contraction of jets in comparing the theoretical and measured flow through orifices and Euler was the first to consider cavitation in connection with the design of water turbines. The progress made in the 18th century is truly remarkable and it makes a fascinating story. The history is completed by chapters on the 19th century, the rise of fluid mechanics in the 20th century and an appraisal of the present situation at mid-century. Somehow the advances made in the 19th and 20th centuries lack the romance and glamour of the earlier golden age but the practical contributions, particularly to engineering, are nevertheless very great.

In the 18th century the distinguished tradition of the French Écoles was clearly established by the remarkable numbers of very eminent hydraulicists which they produced. Because of the easier availability of French records for this period, there may be a tendency to neglect the work of other countries during this time. Balance is always difficult to preserve, particularly in such a concise history, and although one may have doubts here and there, the authors have maintained a good general level of equilibrium.

Most of the important figures seem to have been mentioned, although a few distinguished names may have been omitted because they did not come within the particular scope of the book. Perhaps some mention should have been made of such names as Stodola, Schoklitsch and a few others.

This book provides a good many details which present-day scholars miss by not having easy access to original or translated versions of the great technical works. How much is lost by reference to second-hand and often incorrect versions resulting from successive generations of textbooks ! " One of the ironies of history is the fact that Froude's name has since become inseparably associated with a law of similarity and a non-dimensional number, the first of which he did not originate and the second of which he never even used." The authors have rendered a service by pointing out such anomalies and by quoting direct from old works whenever possible.

The standard of printing is high, and there are many illustrations, including reproductions of portraits of the outstanding figures. The book is written in a concise and easily readable style and is remarkably complete and well-documented for a brief survey. In fact, it whets the appetite for a larger version and it is to be hoped that the authors may consider writing a more detailed history on the same lines. To all those wandering in the maze of modern technology, this history of hydraulics is warmly commended.

S. P. HUTTON

Fundamentals of Gas Dynamics, edited by H. W. EMMONS (Volume III of High Speed Aerodynamics and Jet Propulsion). Princeton University Press, 1958. 749 pp. $20.00.

Here is a book written by some of the world's experts on gas dynamics. The result, as one would expect, is a book of great value which will be used continually by everyone interested in the subject. It must also be said, however, that this reviewer found it disappointing in a number of ways. This should not be unduly emphasized, and if a relatively large amount of space is devoted here to points of adverse criticism, it is with the understanding that the reader does not need or want to be told many times that articles by people like T. von Kármán and G. I. Taylor have much to offer!

The eight main sections are:

A. The equations of gas dynamics (Tsien).

B. One-dimensional treatment of steady gas dynamics (Crocco).

C. One-dimensional treatment of unsteady gas dynamics (Kantrowitz).

D. The basic theory of gas dynamic discontinuities (Hayes).

E. Shock wave interactions (Polachek and Seeger).

F. Condensation phenomena in high speed flows (Stever).

G. Gas dynamics of combustion and detonation (von Kármán, Emmons, Tankin, Taylor).

H. Flow of rarefied gases (Schaaf and Chambré).

One of the main criticisms is that these sections remain essentially separate, each one having a different purpose and scope, and a different assumption as to the type of reader. The material is not combined into a connected comprehensive account. There are practically no cross-references between sections, and there is considerable duplication. All this could have been just a minor irritation but it turns out to be more. For as a consequence, the value of some articles is reduced, matter of interest is left out and some basic questions emerge confused. Let us consider the articles in turn.

A first section of the standard type on the equations of motion is appropriate if the book is planned as a complete account that a newcomer would read. But the later sections (with the possible exception of C) are not of that type. Thus A loses much of its value. Most of it is in fact not used at all in the rest of the book; each section rederives the few equations needed from first principles. There would be a good case for omitting the section altogether (since there is no shortage of references) and replacing it by a careful review of the results of kinetic theory, the physical chemistry of dissociation, etc., topics which have become so important and yet are not familiar to many gas dynamicists. (It is true that Vol. I of the series is *Thermodynamics and Properties of Matter* but that is another 700 pages!).

Although a detailed discussion of the contents of each section would be too long, it must be noted that some of the derivations in A are misleading and some appear to be wrong. For example, in deriving the energy equation (pages 10 and 11), the work done by the stresses π_{ij} per unit time per unit volume is calculated to be $\pi_{ij}\,\partial u_i/\partial x_j$ instead of $\partial(\pi_{ij}u_i)/\partial x_j$; the resulting equation is correct because the increase of kinetic energy is also omitted from this energy equation. In the treatment of Helmholtz's equation for the vorticity $\mathbf{\Omega}$ (pages 30 and 31), the term $(\mathbf{\Omega}\,.\,\nabla)\mathbf{u}$ is interpreted as a 'bending' of vortex lines and the term $-\,\mathbf{\Omega}(\nabla\,.\,\mathbf{u})$ as the 'stretching'. This is wrong, of course; the former represents the stretching as well and the latter would be absent altogether in incompressible flow. The so-called 'intrinsic coordinates' n, s, the distances along and perpendicular to streamlines, are used on pages 53, 61 and 63. These variables cannot be introduced in the large and

$\partial/\partial n$, $\partial/\partial s$ are not derivatives in the usual sense; they stand for $h_1^{-1}\,\partial/\partial\alpha$, $h_2^{-1}\,\partial/\partial\beta$, where α and β are generalized coordinates defining the streamlines and orthogonals, and $h_1\,d\alpha$ and $h_2\,d\beta$ are the line elements; for instance $\partial/\partial s(\partial f/\partial n) \neq \partial/\partial n(\partial f/\partial s)$. A final example: the equations of motion are deduced by considering conservation of mass, etc., for a parallelepiped, and are then integrated over an arbitrary volume, the results being *interpreted* as conservation laws. Why not treat an arbitrary volume in the first place ?

Section B is a complete book in itself. It is nearly 300 pages long, out of about 750 for the whole book, and is completely independent of the rest. All aspects of one-dimensional steady flow are developed and applied in considerable detail. This must surely be the most thorough treatment that exists. Particularly impressive is the amount of useful information that can be got out of rather a small number of basic ideas, supplemented by careful physical arguments. There are many practical applications, some of which are far from one-dimensional at first sight. Like most of the other articles, great care is taken to be realistic about the thermodynamics; after reading this book, it will be almost embarassing to assume $p \propto e^{S/c_v}$. This section is perhaps more suitable for reference as needed than for continuous reading; reading it from beginning to end required some persistence.

In contrast to B, section C is relatively short and not compendious, with a general reference to *Supersonic Flow and Shock Waves* by Courant & Friedrichs for full mathematical details. Here some of the space wasted elsewhere in duplication could have been used. For instance, Riemann's classical solution for the interaction of two simple waves and the hodograph transformation are mentioned only in a footnote. On the other hand, there are some physical arguments about simple waves, with or without weak shock waves, and Professor Kantrowitz's original work on the stability of shock waves in steady channel flows, which do not appear in Courant & Friedrichs. It should be noted that this particular section was written in 1952 and as a consequence is a little out of date now.

Part of D is concerned with the Navier–Stokes structure of shock waves. This is very well done and indeed some of the original ideas, such as the precise use of Burgers's equation, have less impact than they deserve because they were introduced independently, but published earlier, by Lighthill in *Surveys in Mechanics* (the G. I. Taylor 70th Anniversary Volume). It is disappointing, however, to find that the kinetic theory approaches to the question are not also included in some detail. The author claims correctly that their foundations are a little shaky and their results seem to be less successful than the Navier–Stokes treatment, but these are not sufficient reasons unless space is scarce. But space is used elsewhere on much less respectable theories, and section B is certainly not limited in this respect. After all, the beginner can find the classical treatment of shock structure in many books, and the more experienced reader would welcome an authoritative account of some of the more recent attempts just because they do pose considerable difficulties.

The remainder of D concerns ' discontinuities ' in which reactions and change of state occur, examples being condensation shocks, flame fronts and detonations. This has to be considered in conjunction with sections F and G where these topics are studied in detail. Now, F and G make no serious reference to the longish discussion in D; instead there is appreciable overlap. For example, the classification of combustion phenomena into weak and strong deflagrations and detonations is given in D3, G1 and G10, in each case as if for the first time. Both D3 and G10 include detailed discussions of the properties of the Hugoniot curve which are essentially the same. The equations for a plane stationary flame front are given in both G1 and G2 (which are by different authors) in different form and notation without explaining why this was necessary. In a difficult and only partially understood subject, the lack of a unified treatment is very confusing. Moreover, what is the relation of these articles on combustion to Vol. II of the series which is an equally large volume devoted *entirely* to combustion ?

The interesting question of the existence of strong deflagrations and weak detonations is clouded by some of the statements. After referring to Friedrichs extensively in the arguments suggesting that strong deflagrations cannot exist, the final paragraph of D6 begins: " With regard to the weak detonation, which has not been observed (again to the writer's knowledge) in explosion experiments, there is no theoretical evidence for non-existence." Yet such evidence is given in Courant & Friedrichs and on p. 231 of their book there is the italicized statement: " Consequently, weak detonations are impossible." I am open to arguments that their reasoning is unsound but not that it is not there.

Of course, in spite of the above criticism, F and G are bulging with information, and one can really get some idea of the present state of these complicated fields. There is again the feeling of reality which is an outstanding feature of the book. For example, in G10 we are led through the details of calculating the Hugoniot curve for the mixture $H_2+\frac{1}{2}O_2+2{\cdot}5N_2$, first without and then with dissociation, before going on to discuss the propagation of detonation waves. At every stage there are checks with whatever experiments are available.

Section E requires little comment. It is a complete account of the present knowledge of the interaction of plane shock waves with other waves, solid walls and interfaces. The methods of deriving theoretical formulae, the subsequent computations, the comparison with experiment (and lack of agreement for Mach reflection of weak shocks) are all set out exactly as they should be.

The final section H stands out as a piece of careful exposition. All the ideas and results are presented clearly and concisely; it makes interesting and informative reading. It even remedies earlier deficiencies in part. For example, the section on slip flow contains an excellent review of the derivation of the Navier–Stokes, Burnett and Thirteen-moment equations from the Boltzmann equation, with a sober consideration of the validity and degree of success of the various approximations involved. This is of general value for the book, quite apart from its relevance to slip flow. Some brief comments on shock structure also appear here. Odd though it may seem, section H was added on to this volume as an afterthought; it was originally prepared for Vol. IV.

After a classification of the various flow regimes, with the significant relative magnitudes of Mach number and Reynolds number, section H is divided into three main sections; free molecule flow, slip flow, and experimental results in slip flow and transition regimes. The first of these shows how theories of the heat transfer and the forces, for bodies moving at the appropriate high speeds, may be developed assuming a Maxwellian distribution about the main stream velocity for the molecules incident on the body surface and using empirical coefficients to specify the interaction of the incident molecules with the surface. Typical cases are worked out and detailed references are given for further work. In the chapter on slip flow, the review noted above is given and the conclusion reached that the Navier–Stokes equations, together with the slip velocity and temperature jump boundary conditions, are at present more successful than any of the intended improvements. The final chapter sets out the comparison of theoretical results worked out in this way with experiment.

G. B. WHITHAM