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# REVIEWS

## Internal Fluid Flow: The Fluid Dynamics of Flow in Pipes and Ducts. By A. J. WARD-SMITH. Oxford University Press, 1980. 566 pp. £36.00.

'The purpose of this book is to provide a comprehensive and systematic account of fluid flow in pipes, components, and internal flow systems. It is intended as a source-book of information suited to the needs of designers, researchers, teachers, and students engaged in engineering and the applied sciences.'

These are the sentences with which Ward-Smith starts the Preface to his book, and in this review I shall attempt to assess how successful he has been. I shall also try to set this book in the context of related texts. The author makes the point 'that there was no English-language book in print which treated the subject as a whole' when he set out to write this book. This is no longer the case and it may be useful to readers of this review to offer some comparisons with related works.

*'a comprehensive and systematic account of fluid flow in pipes, components, and internal flow systems'*

After a General Introduction the book is divided into 3 parts: Part 1, Mathematical Foundations (Chapters A and B); Part II, The Fluid Dynamics of the Component Parts of a System (Chapters C–L); Part III, Factors Relating to Over-all System Performance (Chapters M & N). The book also has the benefit of a list of symbols, which I find invaluable in referring to a book with the minimum of frustration, a list of about 350 references, and an index which should improve access to the extensive information collected here.

The *General Introduction* is aimed at assisting 'the casual reader to dip into the book for specific items of information'. In 19 pages the author covers physical properties of fluids, Reynolds number and other parameters, and general flow features. As well as a brief discussion of laminar, turbulent and transition flows he explains certain emphases of his approach. He sees a detailed treatment of turbulence as out of place owing to rapid changes of attitude. He observes that current effort has moved away from the semi-empirical theories of Prandtl, von Karman and Taylor to analytical methods which account for production, convection, diffusion and dissipation of turbulence. His brief discussions of turbulence and transition are useful.

The first main part of the book is divided into Chapter A, Fundamental equations of fluid dynamics and thermodynamics, and Chapter B, One-dimensional gas dynamics. Since derivations of the equations appear in other texts, the author plunges straight into a three-dimensional statement, first of the continuity equation and then of the momentum equations, the stress tensor and then various forms of the complete equations in cartesian co-ordinates. He then goes on to set the equations out in orthogonal curvilinear and cylindrical co-ordinates. After the special cases of axisymmetric flow and creeping flow, a very brief (8 page) review of thermodynamics leads in to the treatment of the energy equation. Chapter A continues with the derivation of $\phi$ the potential and, together with $\psi$ the stream function, its relation to complex analysis, and $\psi$ for axisymmetric flow. The full statement of the Reynolds stresses and their summary in tensor notation follows. The integral statement of the equations with control surface and average cross-sectional properties concludes the chapter on a slightly lighter note. Chapter B provides in 58 pages a fairly standard mathematical coverage of one-dimensional gas dynamics. Nozzles, Fanno and Rayleigh processes are discussed together with generalized flow, shocks, normal and oblique. Apart from a brief reminder at the end of the chapter concerning the assumptions made, the treatment is based on the equations and little note is taken of physical limitations.

Part II is about 60 % of the book and treats in turn straight pipes, entrance regions, bends, diffusers, contractions, differential-pressure flowmeters, branches and junctions, swirling flow, and gauzes and baffles. Chapter C starts with a good treatment of fully developed flow in circular pipes and brings together all the standard material together with friction factor charts, a table of equivalent sand roughness and methods for the inverse design problem (knowing pressure drop, find the diameters, etc.). The final part of the chapter covers non-circular ducts giving exact solutions for laminar flow for some sections, and a few data and correlations for turbulent flows. Reference is also made to some numerical solutions. A table of equivalent diameters and friction coefficients is included to allow circular pipe data to be used for loss calculations in non-circular pipes and ducts. The chapter concludes with a brief discussion of compressibility effects.

The first 60 % of Chapter D is concerned with approximate analytical solutions of the entrance region for laminar flow, although the author admits that the volume of 'literature is not justified by the intrinsic importance of the subject matter'. Again it is a useful collection of relevant work. The last 40 % is concerned with turbulent flow and non-circular ducts. The turbulent treatment appears to lack some recent work.

Chapter E discusses the general features of flow in bends, the equations and their solution for laminar flow including reference to numerical approaches. There is a brief discussion of turbulent flow, and flow in non-circular ducts. Short circular arc bends in which a steady flow pattern is not achieved are discussed and the effect on pressure drop of tangent length, Reynolds number, and inlet velocity profile is given.

Chapters F and G follow the pattern set by the previous chapters and offer a mixture of physical explanation, analytical solution for laminar flow and experimental results providing for the needs of the designer. Geometrical variations cover two-dimensional diffusers with straight walls, conical diffuser, annular diffusers, and sudden enlargements, guide vanes and cropped diffusers. The range of contractions considered is less extensive.

Chapter H, on differential and pressure flowmeters, provides a useful and clear description of their operation and the main factors affecting their calibration. The chapter covers compressible flow and flow at Reynolds numbers down to 10 as well as the more common operating ranges for orifice plates and a briefer treatment of the venturi and the nozzle with a comparison of the devices. The chapter also includes sections on other devices (such as segmental orifice plates and Dall tubes), on flowmeter choice and on critical nozzles. Chapter J on branches and junctions is essentially a discussion and presentation of the experimental data.

Chapter K on swirl compares theory and experiment for laminar flow and gives a general description of turbulent flow with swirl. The decay of swirl and the apparent friction factor are discussed. A description of the mode of operation of the vortex tube closes the chapter. Chapter L on gauzes and baffles gives a useful review of correlations and of data. A brief section covers reduction of flow non-uniformity, and refers to flow deflection and the generation of special flow characteristics. A final section mentions flow straighteners.

In Part 3, concerned with the system as a whole, Chapter M provides guidance on calculation of pressure losses along flow paths consisting of various components and forming a part of a network, while Chapter N gives a brief introduction to pumps and fans (about 25 pages) to complete the system components. The discussion is confined to rotodynamic machines and covers performance characteristics, the interaction of machine and system, selection, instability, etc. An Appendix contains gas tables for $\gamma = 1{\cdot}4$; one-dimensional, shock, Fanno and Rayleigh flows.

*'It is intended as a source-book of information suited to the needs of . . . researchers, teachers and students'*

I have already found this book a valuable reference and I have no doubt that it will provide a source-book for lecture preparation. I also feel certain that as an introduction for researcher or student it will point the way and give the best start that can reasonably be asked of a book. In suggesting this I do not wish to imply that the author's references to other work are complete, or necessarily that his treatment is always equally well balanced. There are certainly omissions and anyone embarking on the subject would presumably start with his/her own literature survey. However, as a statement by someone who has attempted to keep abreast of the literature, it is valuable.

*'. . . designers . . .'*

I do not feel that the designer will find in this book information in a form which will ease his task. Some of the information he needs is here, but is not very easy to extract. Much that he might like does not seem to be here. I wonder how realistic it is to expect a designer, working against time to finish a design, to wade through, for instance, the 49 pages on diffusers to find the 6 or so which are needed in design. That typical design data is included is important for the sake of the student and researcher. Whether the importance of that data and the need for its improvement are lost amongst elegant laminar flow solutions of far less practical value is less certain.

*'. . . there was no English-language book in print . . .'*

Two other books known to the reviewer are now available: *Internal flow systems* by D. S. Miller, published by BHRA Fluid Engineering (1978), and *Fundamentals of pipe flow* by R. P. Benedict, published by John Wiley (1980). It is useful to set Ward-Smith's book in the context of these two. Benedict's book does not claim to be for the specialist and its coverage is wider and less deep than Ward-Smith's. Thus more general boundary layer discussion is included; flows of liquid–vapour mixtures in pipes; and an extensive section on thermodynamic measurements in pipes including temperature, pressure and flow. With such a wide coverage some is of necessity superficial but the overall result may be more attractive to the newcomer to the subject. The many worked examples (there are none in Ward-Smith's) will be useful. The designer is also likely to find Benedict easier to use since the basic design information is collected together in about 76 pages.

If Benedict moves nearer to the needs of the designer, Miller moves all the way and provides a text which is unashamedly aimed at the designer. Much emphasis is placed on a physical understanding of the flow and the presentation of the origins and nature of the loss mechanisms with virtually no recourse to mathematical descriptions. The results in a text which is concise, allowing the designer to master the elements and apply the data. The text is also interspersed with examples. The loss data is all consigned to Part II of the book where it is easily accessed. The only subjects covered which are not in Ward-Smith's book are cavitation and transient analysis. The other value of a book like Miller's is that it allows the teacher to identify industry's needs and the researcher to apply his work to improve industry's methods.

I am fortunate in possessing both Miller's and Ward-Smith's books. The designer will want Miller's book, the researcher Ward-Smith's. But for a single introductory student text, Benedict should be seriously considered.

R. C. BAKER

## Mathematics Applied to Deterministic Problems in the Natural Sciences.

By C. C. LIN and L. A. SEGEL. Macmillan, 1977. 604 pp.

This book describes various aspects of applying mathematics to problems in the natural sciences, beginning with physical descriptions of the problems and ending with physical interpretations of the mathematical results. About nine such problems, many of which have not appeared in a text book before, are treated in the first two parts of the book, while the third part comprises an introduction to the theory of continuum mechanics with some associated problems which will be very familiar to *J.F.M.* readers. This final part is a good introduction to the book's successor, which is a more conventional volume and is described later.

All the material, both physical and mathematical, is introduced at freshman level and this is the principal reason why the book is so long. However, the authors are ambitious enough to have sprinkled many lists and footnotes throughout the text indicating important areas of current research, but many of these will be lost on beginning students. The general approach is typified by the large number of exercises with carefully thought-out answers and the plethora of footnotes containing pieces of advice about applied mathematical philosophy.

I must admit my first reaction was certainly one of exasperation at the number of pages devoted to describing seemingly trivial problems and typified by the introduction to singular pertubation theory where $2\frac{1}{2}$ pages are devoted to the solution of $\epsilon m^2+2m+1 = 0$, $0 < \epsilon \ll 1$. However, as a sincere effort to communicate what applied mathematics has to offer to would-be students, the book must be assessed at a deeper level. In doing this, there is a danger of becoming involved in arguments about philosophy and style which may be quite irrelevant to the central question of how students will react to the material. I will avoid the philosophical questions although the book contains several revealing passages about what excites the intellectual curiosities of pure and applied mathematicians. Suffice it to say that the authors pursue each problem they describe until a 'thorough understanding' of the mechanisms involved has been gained.

Concerning questions of style, a great deal could be written about, for example, the following:

(i) Whether to proceed from special cases to general theories or vice versa. Here the authors' answer is clearly the former, and this view will be endorsed by many students as being the best way of learning about physical processes.

(ii) How much abstraction and vision of what goes on in the pure mathematical world should be allowed. The authors are not too generous here, which will probably earn them the gratitude of most students.

(iii) To what extent individual pieces of theory should be self-contained. The authors try very hard to avoid reliance on other sources.

(iv) How many different possible physical mechanisms should be listed when constructing a mathematical model. Too many will cause confusion, but the authors general prefer to take this chance rather than to leave things unsaid.

(v) Whether to try to achieve unity by grouping problems by means of physical or mathematical analogy. Here the authors prefer the former but their footnotes draw many analogies of all types throughout the book.

(vi) How much historical content should be permitted; here there are many especially well-selected items.

(vii) What balance to achieve between classical and unconventional problems. This volume focusses on the latter but its successor is devoted to the former.

I expect few people will agree with the authors' judgement on all these questions of style, but their mastery of the subject is such that many will find at least some aspects of the presentation greatly to their liking. Certainly I was disappointed in the discussion of matched expansions and the expense of achieving completeness by the insertion of chunks of theory such as Picard's theorem and Fourier series, which are readily available elsewhere. But equally there is widespread use of delightfully far-fetched but appealing analogies, a beautiful illustration of macroscopic theories based on Brownian motion, and the accounts of stability theory and diffraction are models of clarity. All the examples are described in a modern and frank way using numerical methods where necessary and the book makes a startling contrast say to Jeffreys & Jeffreys.

However, at the end of the day all these niceties seem irrelevant in relation to the authors' basic aim of describing the construction and analysis of mathematical models as clearly as possible for the student. I am sure the most difficult part of the task they have set themselves is the description of how a model is set up and for many beginners it is almost impossible to be too painstaking over this. Despite the joyless way in which some parts of the book may appear to read, the thorough descriptions which the authors have given of examples from biology, chemistry, physics and engineering will surely prove a great boon to future generations of students. Many of these students would otherwise be resourceless or at best have to learn modelling by far more haphazard routes.

J. R. OCKENDON

**Mathematics Applied to Continuum Mechanics.** By L. A. SEGEL, with material on elasticity by G. H. HANDELMAN. Macmillan, 1977. 590 pp. £16.45.

This self-contained volume is a continuation of the one reviewed previously inasmuch as its principal aim is to communicate to the student what is really involved in applying mathematics to practical situations. Here the practical situations are those of fluid and solid mechanics rather than the more varied and less classical models considered earlier.

The book's style, as in the preceding volume, relies on hiding as little from the reader as possible. The candour which is such an important ingredient in explaining modelling to new students is carried to extremes in the revelation, in the body of the book, that the idyllic wave pattern seemingly produced by a swimming water beetle in the frontispiece is in fact generated by suspending a dead beetle in a flowing stream!

More important, the presentation is ideally suited to those topics which the authors have decided to cover in depth. There is an initial introduction to linear transformations and tensors, followed by an account of some aspects of viscous flow at high and low Reynolds number. Next comes a lengthier description of elasticity, mostly linear but both static and dynamic, and then 150 pages on surface gravity waves, again mostly linear but with an emphasis on surface tension effects. This latter material is described in a coherent and self-contained way which is impossible to find elsewhere except in lecture notes. All these topics are excellent vehicles for trying to excite a potential student's interest in applied mathematics. The book concludes with an account of variational methods and an introduction to applied functional analysis which seems slightly out of place. Nonetheless, as a self-contained introduction to the calculus of variations, with all the usual grey areas exposed as fully as space permits, this section reads very easily for applied mathematicians.

As with the earlier volume, there are questions of presentation even though fewer facets of applied mathematics are shown here. Certainly the only aspect, of any substance, that I found irritating was the insistance on the use of velocity and pressure as dependent variables for describing gravity waves lest they be rotational. The choice of Wilton's ripples to illustrate nonlinear effects appears idiosyncratic at first, but is very sensible considering the space that would have been needed to do justice to shallow-water theory or solitons. I admired the authors' frank contrast between mathematical and engineering elasticity, as illustrated by bending beam theory, and the uncluttered account of ship wave theory.

In summary, the book is more conventional than its predecessor but conveys even more graphically the impact of applied mathematics on some everyday situations arising in the real world. I hope that one day the authors may have time to present other areas of applied mathematics, say quantum mechanics, in a similar way.

J. R. OCKENDON