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BOOK REVIEWS

Fields, Flows and Waves: An introduction to Continuum Mechanics. By D. F. PARKER. Springer, 2003. 270 pp. ISBN 1 85233 708 7. £15.95 (paperback).

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Continuum mechanics is concerned with the collective behaviour of a very large number of objects. Classically, these objects have tended to be atoms or molecules, but this averaging process may be equally well applied to cells in the human body, traffic flow, electricity, light and sound.

This is another excellent readable book in the Springer Undergraduate Mathematics Series (SUMS). It is a refreshingly modern approach to Continuum Mechanics and has been based on ten years experience of delivering courses at the University of Edinburgh. Indeed Professor Parker has written this book so that it might be used directly as an elementary course (Chapters 1–5) or, if Chapters 6–10 are included, a more advanced undergraduate course. This is a carefully written, well structured book which contains a wealth of examples complete with solutions.

A minimum knowledge of the calculus of several variables is required, as is the concept of the gradient of a scalar. Armed with these elementary tools the reader can proceed. Chapter 1 provides an overview of the continuum description, introducing conservation and balance laws. Chapter 2 deals with unsteady heat flow; fields and potentials are introduced in Chapter 3; and Laplace's equation and Poisson's equation are discussed in Chapter 4. In the next chapter waves are first introduced through the motion of an elastic string. Chapters 6 and 7 treat the elements of fluid flow and elasticity respectively, while Chapters 8 and 9 deal with vibrations and waves and electromagnetic waves and light.

The recurring theme of waves flows throughout this book. Chapter 10 treats chemical and biological models continuing the theme with the introduction of travelling wave fronts and spiral waves.

The Oxford Study Groups with Industry have had a distinct influence on modernising applied mathematics, both in the United Kingdom and abroad. Their spirit is embodied in a number of books, for instance: A. B. Tayler's *Mathematical Models in Applied Mechanics*; A. Fowler's *Mathematical Models in the Applied Sciences* and N. Fowkes' (with J. Mahoney) *An Introduction to Mathematical Modelling*.

These three books all contain interesting material based on novel mathematical models developed for, or at least influenced by modern industry.

The spirit of the Study Groups is also there in Professor Parker's book, but here we have a carefully structured book from which a modern undergraduate applied mathematics course may be taught directly.

SEAN MCKEE

Breakup of Liquid Sheets and Jets. By S. P. LIN. Cambridge University Press, 2003. 286 pp. ISBN 0521 806941. £55 or $75 (hardback).

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The ubiquity of free-surfaces flows in the environment, as well as their importance for industrial flows, hardly needs to be emphasized. Jets and sheets are the natural building blocks of such flows, and are very easily driven unstable either by surface tension or by shear from the external gas. After what is often a complicated sequence of instabilities, the fluid ends up in its more or less inert form: drops. The first quantitative observations of liquid sheets and jets were reported in 1833 by Félix Savart in a series of ground-breaking papers. The important contributions of Joseph Plateau notwithstanding, it has been the linear stability analyses of Lords Rayleigh and Kelvin that have continued to set the tone for most of the research in this area to the present day.

This monograph by S. P. Lin, Professor of Mechanical and Aeronautical Engineering at Clarkson University, consists of two parts: the first, which is by far the most substantial, is a thorough presentation of the linear theory of liquid sheets and jets, laid out in turn; the second is a brief survey of recent studies of the nonlinear behaviour of liquid jets. In the first part, after a short introduction stating the equations governing incompressible fluid motion, the simple case of uniform inviscid sheets is used to introduce one of the main recurring themes of the book: absolute versus convective instability. This is an important distinction, since jets and sheets are usually rapidly moving relative to the surrounding gas or the nozzle they emerged from. Thus a liquid jet is typically (absolutely) stable at a short distance behind the nozzle, but (convectively) unstable if one follows disturbances being convected downstream, and as revealed by the presence of drops.

The book then treats sheets expanding horizontally or being stretched under gravity, viscous jets, and the beautiful stationary wave patterns on liquid sheets brought about by a balance between wave propagation and convection. In a similar vein, the stability of inviscid and viscous jets surrounded by a (compressible) gas is treated next, as well as annuli between two fluids. The final two chapters, which comprise the second part of the book, provide a very short but informative survey of nonlinear phenomena, which dominate the dynamics close to pinch-off. Most characteristically, this leads to satellite drops, which form from elongated ligaments between two main drops. Although already well known in the 19th century, their existence is not predicted by linear theory. Very recent results include a molecular dynamics simulation by Moseler & Landman (2000), of a jet only six nanometres in diameter.

The author must be given great credit for assembling a vast amount of material on a common theme, including a very extensive bibliography, which is not available elsewhere. Having made significant contributions to the linear stability of sheets and jets himself, he offers an authoritative opinion even on some contentious matters. In each section, the problem is laid out in great generality, and treated clearly and methodically. The presentation is gratifyingly free of the specialised jargon of many engineering texts, which will make it more accessible to readers coming from other disciplines. I found myself almost longing for the comfort of some of the more familiar terminology like ‘Navier–Stokes equation’.

Unfortunately, in spite of some enticing words to the contrary on the cover, hardly any physical explanation of the instabilities is provided, and there is a lack of an overarching concept connecting the different problems. For example, upon introducing sheet instabilities, nothing is said about the physical mechanisms that drive sheets unstable, or the role the external gas plays in it. As for surface tension, not even the fundamentally different role it plays for sheets on one hand, where disturbances always increase surface area, and jets on the other, where surface tension drives instability by pinching the jet, is explained.

In my view the most disappointing failure of the book is, however, its unconvincing exposition of the mathematical treatment of point-wise disturbances, used in most of the subsequent chapters. Following the mathematical argument involves constant references to families of dispersion curves in complex wave-number space, whose significance I don't understand, and to integration paths, which I can't picture. While this book will have readers with a better mathematical background than mine, I wonder about the broad readership coming from disciplines such as chemistry or medicine the author seems to have in mind.

Although this book is written from a theoretical perspective, the author tries as much as possible to compare to available experimental data, and to use photographs for illustrative purposes. The main conclusion I draw from this very useful compilation of experimental data is that many more experiments need to be done. I found almost no example in the book of a truly convincing confirmation of linear theory, except perhaps of Rayleigh's calculations of surface- tension-driven instability, and I have experimental colleagues who insist that even for that problem many questions remain open. Perhaps it is also telling that the most striking pictures in the book are due to G. I. Taylor, and were taken almost 50 years ago.

Considerable space is devoted to the influence of air on jet breakup, yet I found little critical evaluation of the ultimate success of these efforts. To obtain agreement between theory and experiment, Sterling & Sleicher (1975), in the most-often cited paper on the subject, had to multiply the term associated with the outside gas by an adjustable factor. In my view, this is proof that the theory *does not* describe experiment, but the reasons for this discrepancy remain unexplained. At high speeds, linear theory is used to predict the angle at which tiny spray droplets are ejected from the jet. This seems to be stretching the capabilities of a linear theory far beyond its limits. A more careful evaluation of nonlinear effects would also have been in order for the treatment of encapsulation, which crucially includes a change in topology.

As for the bibliography, a lot more care could have been devoted to the rendering of foreign-language names and titles. This complaint may be a pet peeve of mine, but why is it that *not a single* French or German title is rendered correctly? Plateau is spelled "Platou" in the text, Cosserat "Cosarat", and Galileo is consistently dubbed "Galeri". Each of the three times Plateau's famous monograph, *Statique expérimentale et théorique des liquides soumis aux seules forces moléculaires* is cited, it is butchered in a new and innovative way.

I am also concerned about the author's tendency to raise what seem to be serious issues, without telling the reader what they are. For example, to explain why he reserves the names of both Rayleigh and Taylor to characterise the breakup of jets: "This is because the author, following Taylor and Rayleigh, views the formation of drops and droplets as a consequence of interfacial instability, although Savart (1833), Plateau (1873), and others studied the problem from a different point of view." Well, since the two main detractors of "interfacial instability" lived in the 19th century, the author's views apparently carried the day. In introducing jet breakup, non-circular orifices are discussed very briefly, and Lord Rayleigh and G. I. Taylor are cited as if they had very different explanations for the same phenomenon. However, the periodic disturbances caused by surface tension (Rayleigh), and the formation of a sheet by converging streamlines (Taylor), only bear a superficial resemblance to each other, a fact perfectly clear to Taylor. The importance of surface tension for the generation of periodic disturbances is perhaps best illustrated by the work of the young Niels Bohr (1906), who used Lord Rayleigh's method to obtain quite an accurate value for the surface tension of water, later published in a very careful and interesting, yet rarely cited paper for the *Philosophical Transactions of the Royal Society*.

In conclusion, despite the shortcomings described above, I am glad the chance to review this book left me with a valuable source of information on free-surface flows. I hope its publication will stimulate more experiments in this fascinating area of fluid mechanics.

REFERENCES

Bohr, N. 1909 Determination of the surface-tension of water by the method of jet vibration. *Phil. Trans. R. Soc. Lond.* A **209**, 281–317.

Moseler, M. & Landman, U. 2000 Formation, stability and breakup of nanojets. *Science* **289**, 1165–1169.

Sterling, A. M. & Sleicher, C. A. 1975 The instability of capillary jets. *J. Fluid Mech.* **68**, 477–495.

Jens Eggers

Computational Models for Turbulent Reacting Flows. By R. O. Fox. Cambridge University Press, 2003. 438 pp. ISBN 0521 650496, £80 or $120 (hardback); ISBN 0521 6590780, £39.95 or $55 (paperback).

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Turbulent reacting flows occur both in chemical reaction engineering – the province of chemical engineers – and in combustion – studied, predominantly, by mechanical and aerospace engineers. Three essential aspects of these flows are:

1. their spatial inhomogeneity;
2. significant turbulent fluctuations of composition and temperature;
3. complex reactions which proceed on a range of time scales which may overlap the range of turbulent time scales.

Historically, the chemical-engineering and combustion communities have put different emphasis on these different aspects; and, to make the problem tractable, they have made simplifying assumptions on other aspects (e.g. assumptions of homogeneity, perfect micro-mixing, or equilibrium chemistry). As Fox argues, it is now possible to account appropriately for all three of these aspects; and hence it is now valuable to draw together, in a unified framework, the contributions of the two communities.

The appropriate theoretical framework is provided by the composition PDF, i.e., the single-point probability density function of the fluid composition and temperature. This PDF fully represents the turbulent distribution of compositions as a function of position and time; and its transport equation has the invaluable property of representing arbitrarily complex, multi-step reactions in closed form. The two major chapters in this book are: Chapter 6, which describes the use of the PDF transport equation in CFD; and Chapter 5, in which other modelling approaches are explained in terms of explicit or implicit assumptions made about the form of the joint PDF. Over the last 20 years, the transported PDF approach has been developed and applied primarily for combustion; but, interestingly, the most widely used mixing sub-models originated in chemical reaction engineering 30 and 40 years ago, namely, Interaction by Exchange with the Mean (Villermaux & Devillon 1972) and Coalescence-Dispersal (Curl 1963).

The scope of the book is limited to single-phase flow and to non-premixed reactants. While this represents just a fraction of ‘turbulent reacting flows’, it can be considered the core of the subject, and the area in which our knowledge is most secure, and our predictive capabilities most advanced. The book is published in the Cambridge

Series in Chemical Engineering, and starts from the chemical-reaction-engineering perspective. However, readers from other backgrounds will not find this a serious obstacle. Indeed, the book provides the most complete and up-to-date description of approaches to non-premixed turbulent combustion, and provides a useful complement to the recent combustion texts of Peters (2000) and Poinsot & Veynante (2001).

The introductory chapter (1. Turbulent reacting flows) is followed by three chapters (2. Statistical description of turbulent flow, 3. Statistical description of turbulent mixing, 4. Models of turbulent transport) which present essential background information on non-reactive turbulent flows, especially on turbulence modelling and scalar transport and mixing. Then, in the largest chapter (5. Closures for the chemical source term) a range of approaches are described, including: moment closures; equilibrium chemistry; laminar flamelets; condition moment closures; presumed PDF methods; and transported PDF methods. This last approach is treated extensively in the next largest chapter (6. PDF methods for turbulent reactive flows), which forms the focus of the entire book. The modelling of the transport equations for both the composition PDF and the velocity-composition PDF are comprehensively described; and a useful description is provided of methods such as *in situ* adaptive tabulation for the computationally efficient implementation of the chemistry. The book focuses on models rather than on numerical methods, the exception being the final chapter (7. Transported PDF simulations). The inclusion of this numerical perspective is fully justified because (i) an understanding of the Lagrangian particle/mesh methods is helpful to the understanding of the models, and (ii) a comprehensive account of these methods is lacking elsewhere in the literature.

Through his research over the past decade, Fox has become a master of the material described in the book, and has made significant contributions to the subject. The writing is clear and authoritative, and contains ample historical and modern references. The book is attractively presented and has a good index.

The principle shortcoming of the book is the absence of experimental data. In this field, there is little we can say with confidence unless there is experimental support. Especially for students, it is important to see experimental data, so as to understand the basis for our knowledge and its limitations. For example, in the context of modelling the PDF of mixture fraction by a beta PDF, it is natural to appeal to experimental data to address the questions: What shapes do these PDFs exhibit in different flows? How well are they approximated by beta PDFs? How accurate are reacting-flow calculations based on the beta PDF model? This shortcoming does not seriously detract from the value of the text, as the diligent student can find answers to such questions in the cited research literature.

It is stated in the Preface that “The primary intended audience of this book comprises graduate-level engineering students and CFD practitioners in industry”, and indeed both groups are well-served by the book. The breadth of modelling approaches considered, and the comprehensive background chapters make the book well-suited as the primary text for a graduate course on turbulent reacting flows. Transported PDF methods are becoming increasingly available in commercial CFD codes, and so the latter chapters provide valuable information for the CFD practitioner on these models and their numerical implementation.

REFERENCES

Curl, R. L. 1963 Dispersed phase mixing: I. Theory and effects of simple reactors. *AIChE J.* **9**, 175–181.

Peters, N. 2000 *Turbulent Combustion*. Cambridge University Press.

Poinsot, T. & Veynante, D. 2001 *Theoretical and Numerical Combustion.* Philadelphia: R. T. Edwards.

Villermaux, J. & Devillon, J. C. 1972 Représentation de la coalescence et de la redispersion des domaines de ségrégation dans un fluide par un modèle d'interaction phénoménologique. In *Proc. 2nd Intl Symp. on Chemical Reaction Engineering, New York*, pp. 1–13. Elsevier.

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