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REVIEWS

Introduction to Interactive Boundary Layer Theory. By I. J. Sobey. Oxford University Press 2000. 332 pp. ISBN 19850 6759. £ 45.00.

It is now almost 100 years since Prandtl's profound and timely paper on boundary-layer theory was published. Profound on account of the new insight his work gave to the behaviour of fluid flows at high Reynolds numbers, and timely since aviation was then in its infancy. For a quarter of a century this first-order boundary-layer theory provided a qualitative understanding of flow past bluff bodies and, aided by Pohlhausen's momentum-integral formulation of the equations, quantitative predictions of the flow past streamlined shapes. But by the 1930's deeper mathematical questions were being asked of the theory. For the most streamlined of shapes, namely a finite flat plate, it was shown by Goldstein that the solution at the trailing edge exhibits singular behaviour. Furthermore, evidence was mounting that at a point of separation, defined as a point of vanishing skin friction, singular behaviour could also be expected; the structure of this was finally uncovered some years later by Goldstein and Stewartson. Such singular behaviour only served to emphasize the inadequacy of boundary-layer theory to provide a rational theoretical understanding of high Reynolds number flow past a bluff body. New ideas were needed.

As we now see, with hindsight, these arrived from an unexpected source, namely the interaction between a shock wave and a boundary layer in supersonic flow, with its attendant upstream influence. In his posthumous paper Lighthill (2000) describes the period 1949–1952 as 'a golden age of upstream-influence research', and one which ended with his own seminal contribution. However, in Lighthill's work disturbances to the boundary layer were too weak to promote separation, and almost two decades passed before a more complete picture emerged. One interesting milestone on the way, for incompressible flow, was the work of Catherall and Mangler who demonstrated that, by specifying the displacement thickness and allowing the pressure gradient to adjust, integration through the point of separation could be carried out in a regular manner. In other words, when flow separation is involved the boundary layer can 'control' the flow; this came as no surprise. Later, Sychev placed this on a more secure footing for separation in an incompressible flow by introducing a multi-layered 'triple-deck' structure about the point of separation. This same triple deck had, earlier, both enabled Stewartson and Williams to extend Lighthill's work on shock-wave boundary-layer interaction to disturbances strong enough to promote separation, and Messiter and Stewartson independently to resolve the problem of the singular behaviour at the trailing edge of a flat plate.

For more than three decades now, Prandtl's boundary-layer theory has found its proper place in the hierarchical structure of high Reynolds number flows. The author of the book under review has deemed that the time has arrived for a connected account of these developments to be made accessible, not in the form of a research monograph, but as a graduate text. He takes the view that, notwithstanding the increasing power and sophistication of computational methods for the solution of the Navier–Stokes equations, knowledge of the structure of a flow using asymptotic methods is often vital to an understanding of it. An alternative to this view has recently been put forward by Cowley (2001). The material in the book is limited to two-dimensional, incompressible, steady, laminar flow. It may be noted that a discussion of the breakdown of the unsteady boundary-layer equations would have provided a more complete picture of the limitations of first-order boundary-layer theory.

The first chapter of the book sets the scene with the Navier–Stokes equations and the classical theories of low and high Reynolds number flows, including first-order boundary-layer theory, all within the framework of matched asymptotic expansions. Thereafter the material is divided into three distinct sections. The first on the flat plate, the second on flow separation and the third on channel flows. Within the first two sections the historical context is carefully set out. Thus, the first chapter of the first of these sections is devoted to classical boundary-layer theory for the flat plate including the near-wake region, and the problems associated with it as the trailing edge is approached. The next chapter introduces the triple deck in a systematic, and careful, manner as a resolution of the problem; a final chapter is devoted to the numerical solution of the triple-deck equations. Indeed, a novel feature of the book is the provision of source codes that have been used to generate the data for it including, in many cases, a recalculation of earlier results. These are described in an Appendix (which also includes problems and projects) and made available on the author's web site.

The second section, on flow separation, consists, following a brief introduction, of two chapters, both of which are concerned with separation from a cylinder. The first outlines earlier theories and contains a disproportionately lengthy account of free-streamline theory, in addition to a discussion of the difficulties associated with the boundary-layer equations at a point of separation. This is followed by a chapter on the resolution of the difficulties. First a brief account of the interactive theory of Stewartson and Williams for supersonic flow is given, a situation in which the interaction law is local. This leads on to Sychev's theory for incompressible flow separation where the interaction law is now global. It is unfortunate that the treatment of this is less comprehensive than that of other areas, reference being made to the recently published book by Sychev *et al.* (1998). The chapter concludes with a discussion of global numerical solutions for the flow past a circular cylinder.

The final three-chapter section provides an interesting application of the interactive ideas that have been developed for channel flows. Two chapters are devoted to the flow in channels with non-parallel sides; both asymmetric and symmetric situations are considered. By assuming complex relationships between the (long) length scale of the channel indentations and the (large) Reynolds number it is possible to divide the flow into a core flow flanked by boundary layers with the various regions interactively linked. There is a lengthy discussion of free-streamline flows associated with separation over wall indentations and at an expansion, but unlike Sychev's theory for external flows these apparently have no part to play in the interactive schemes. The final chapter is a largely inconclusive one on the Coanda effect.

There is a sprinkling of typographical errors throughout the book which are largely inconsequential, though the consistent misspelling of Hiemenz, Birkhoff and Poiseuille is an irritant. The author has provided a concise account of interactive boundary-layer theory which those engaged in a study of high Reynolds number flows will find extremely useful. It will sit happily on my bookshelves alongside Rosenhead and Schlichting.

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CD-ROM: Multimedia Fluid Mechanics. Produced by G. M. Homsy, H. Aref, K. S. Breuer, S. Hochgreb, J. R. Koseff, B. R. Munson, K. G. Powell, C. R. Robertson & S. T. Thoroddson. Cambridge University Press, 2000. ISBN 0521 787483. £14.95.

The visual appeal of fluid flows offers marvellous opportunities for teaching. A well-designed classroom demonstration not only serves to remind students that our subject is concerned with real-world phenomena, it also provides a different perspective on an unfamiliar topic, and can sometimes convey a sense of fun or wonder. Many undergraduate textbooks show photographs of fluid flows. Many lecturers illustrate their courses by using Van Dyke's (black-and-white) album, and to demonstrate unsteady phenomena show movies, e.g. the films produced in the NCFMC series.

Homsy and his colleagues have now provided us with a new and powerful teaching aid: a CD-ROM that includes several hundred video clips. The clips are mainly in colour, some are taken from the old films and many are new. There is no audio commentary. The CD is intended to be played, and played with, by individual students on their computers. It is not merely a video library however. The CD places each clip in its appropriate fluid dynamical context by means of a menu-driven subject classification, along with text (in English) and diagrams providing a brief and generally non-mathematical theoretical background. The CD can thus be viewed as a self-tutorial, with moving pictures to illustrate each phenomenon. In places, the CD goes further by incorporating 'virtual laboratory' experiments, where the user is invited, for example, to measure the growth of the Rayleigh boundary layer thickness, or to construct his or her own potential flow from sources, sinks and point vortices. The major topic headings are: kinematics; dynamics, including low-Reynolds-number flows and potential flows; and boundary layers, including separation, instability and turbulence. In addition, biographical notes are provided for some of the founding fathers of the subject.

This CD is an ambitious project, and, in my view, it has been accomplished with remarkable success. Of course no single CD (or textbook for that matter) could be produced that would satisfy the needs of all fluid dynamics students, since they come from widely different backgrounds. The sensible decision has been made here to keep the level of mathematical sophistication low. An indication of that level is provided by the excellent graphical explanations of the meaning and importance of the convective derivative.

I asked my final-year undergraduate class in viscous fluid dynamics to try out the CD for themselves. None of us found any technical difficulty in using it on a PC (Pentium II; on a Pentium I it can be rather slow) or a Macintosh. A shared complaint was that navigation of the tree structure was not always easy to remember and the search facility not always helpful. For example, an attempt to search for the clip showing G.I.'s elegant demonstration of the reversibility of Stokes flow was unsuccessful with ‘reversible flow’, though ‘Taylor’ worked. We also found the use of some scrolling aids counter-intuitive.

More importantly, however, the students reported that the CD had assisted their physical insight (the boundary layer and separation sections were found especially helpful); they found it fun to use; and were already eager for new modules to be produced on, say, wave phenomena or non-Newtonian effects.

In my view, Homsy and his colleagues have performed an excellent service for students and for the fluid dynamics teaching community in assembling this material in a convenient and user-friendly package. The platform that they have established could certainly be built upon further in the future. Such infelicities as remain can be remedied or removed in later editions.

I have no doubt that this CD-ROM should be regarded as a ‘set text’ for viscous fluid mechanics courses at the undergraduate or starting graduate levels. The challenge for lecturers (and perhaps for student libraries) is how best to integrate this material into their courses.

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