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Book review

'Hydrodynamique physique' by E. Guyon, J.P. Hulin, L. Petit, EDP Sciences, 2002, 674 pp., 53.35 Euros, paperback, ISBN 2-86883-502-3.

As P.G. De Gennes, winner of the 1991 Nobel Prize in physics, states in his foreword to this book, fluid mechanics is taught in specialized departments rich in a strong applied mathematical culture and well linked to technological applications. However, the broad physical understanding that G.I. Taylor possessed has become difficult to maintain, and the mathematically formal style of current fluid mechanics texts does not properly prepare inventors of the future who must master the physical phenomena involved in new materials and processes. The present curriculum of students of fluid mechanics tends to ignore superfluids, polymers, colloids, liquid crystals, interfacial phenomena, porous media, chaos, flow structure, granular media and self-organizing phenomena—all subjects in which considerable developments have occurred in the last three decades, many of them at the very foundation of important technological progress.

It is therefore a significant challenge to write a text that captures the flavour of all these topics and meanwhile gives a solid basis for the engineering design and computation of fluid flow in and around such objects as wings, nozzles, jets, turbines, pumps, and the like. To a large extent, this splendid book by Guyon, Hulin and Petit achieves that goal. Its spirited style conveys their enthusiasm for the physical understanding of fluid mechanics, and at the same time mathematical derivations and formulations are rigorously treated. The text is supplemented by a large number of schematic diagrams that help visualize the phenomena. To all this are added the astonishing photographs of flow patterns that rival Van Dyke's Album of Fluid Mechanics and bring the subject alive. The topics selected are well chosen, and are treated in a unified manner. The physics and mechanics of fluids cohabit happily and related topics of particular interest in each discipline are addressed in the same chapter, giving the reader a continuous panorama of the mechanics of fluids. Thus diffusion and convection are treated together and instability, chaos, and turbulence follow one after the other; always the physical content of the material is stressed and clearly explained. The book is enriched by the authors' personal research results. All in all, the authors have achieved their aim of producing a book that describes the widest range of fluid mechanics phenomena in a very original, attractive and accessible way. This excellent book introduces a new view of fluid mechanics and is a welcome addition to the physics and mechanics of fluids literature.

Chapter 1 introduces the physics of fluids. Unique to this book is its treatment of the microscopic aspects of the physics of fluids as a branch of hydrodynamics. Seen from this angle, fluctuations in the immediate vicinity of the equilibrium state of a body (solid, liquid, or gas) not only characterize the state but also tell us about the properties of the return to equilibrium. The simple proportionality relations between the flux (which brings the system back to thermodynamic equilibrium) and the amount of deviation from equilibrium bring in the notion of the transport coefficient, a discussion of which constitutes the bulk of this chapter. It is studied first macroscopically and then microscopically. Heat conduction and mass diffusion smoothly follow this section, and a good mathematical treatment and physical interpretation of the phenomena provide a basis for beginning and intermediate readers. The interfacial phenomena occurring when two fluids are separated by a common surface are then discussed. Wetting and Rayleigh–Taylor instabilities are treated in detail. This chapter finishes with a concise description of optical spectroscopy applied to liquids, by means of which one can measure the diffusive properties of liquids perturbed around their thermodynamic equilibrium state. This chapter bridges the often-observed gap between physicists and mechanists of fluids. It is well illustrated by very nice photographs of wetting, droplets, and interfacial deformations.

Chapter 2 is devoted to a phenomenological description of momentum diffusion and brings the reader to crucial questions of instability and turbulence. The transition from the first chapter to the second and the descriptions of different flow regimes are so smooth that the reader is led naturally to the Landau model of instability, a nonlinear approach usually reserved for advanced readers in the last chapters of fluid mechanics texts. Meanwhile, with the introduction of viscosity as the proportionality constant between stress and shear, the authors describe a microscopic model of viscosity.

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These back-and-forth movements between micro- and macroscopic description are a primary characteristic of the novel school of fluid mechanics exemplified throughout the book.

Chapters 3 and 4 give the mathematical formalism of the bulk of classical fluid mechanics. But special topics are nicely inserted into each section, giving the reader access to such unusual subjects as hydrodynamics of wetting, free surface film flow, the Marangoni effect, lubrification, etc. The Navier–Stokes equations are derived and solved for most steady and unsteady flows. Of special interest in Chapter 4 is the rheology and flow of non-Newtonian fluids. I would say this chapter gives a largely sufficient background in rheology to senior and graduate students in engineering and physics.

In Chapter 3, where the kinematics of flow (velocity field, deformation, Lagrangian and Eulerian approaches) is discussed, the authors take the opportunity to give a good survey of modern velocity measurement techniques (LDA, PIV) and flow visualization. Of course, this is also a good opportunity to show very vivid photos of visualized flows. Chapter 5 on the control volume approach and the exhaustive coverage of inviscid flows in Chapter 6 complete the essentials of fluid mechanics for engineering applications.

The vortex dynamics approach to fluid mechanics is the subject of Chapter 7. The introduction of vortex dynamics is facilitated by the analogy between the velocity field and magnetic excitation field on the one hand, and vorticity and electric current on the other. After covering the basic theorems and techniques, this chapter gives a wide coverage of rotating flows, especially oceanographic and atmospheric flows.

It is in Chapter 8's treatment of low-Reynolds-number flows that the "French connection" between Taylor-style fluid mechanics and that of the authors is most evident. In my opinion, the spirit of G.I. Taylor is present in all chapters of this book, but the low-Reynolds-number flows, by their simplicity, lend themselves especially well to meticulous and ingenious observations. After giving some examples of these flows, the authors discuss a number of their general properties, such as reversibility, additivity, and minimum dissipation that result from the linearity of the Stokes equations. Low-Reynolds-number flow around small particles or ensembles of small particles is then generalised to derive the hydrodynamics of suspensions and porous media. The way in which the latter subjects are so naturally developed from the former is very elegant.

The jump from low- to high-Reynolds-number flows brings the reader from Chapter 8 to 9. Why not? After all, it is another approximation, but at the other extreme of the Reynolds number range: the contrast emphasizes the differences. Not only is the hydrodynamic boundary layer addressed in detail but also thermal and mass transfer boundary layers are treated. Several examples of boundary layers encountered in daily life are given.

Hydrodynamic instability is the subject of Chapter 10. The authors have opted to familiarize the reader with the notion and tools of stability analysis through the well-known example of Rayleigh–Benard stability. A good choice, since it is a system with the basic (subcritical) state at rest, a small detail that makes life easier! However, the discussion is then extended to more complex flows such as Taylor–Couette, Benard–Marangon, boundary layer and interfacial flows. Kelvin–Helmholtz instability receives privileged treatment through a more detailed physical description. The transition to turbulence by the progressive increase of the control parameter sets the scene for the next chapter. This chapter could not be finished, the authors feel, without visiting the scenario of transition to chaos, through successive bifurcation, of systems with a few degrees of freedom.

The book ends with an introductory chapter on turbulence. In addition to the generalities, it gives a good quick treatment of the Kolmogorov theory of turbulence. The authors, however, take the point of view that such in-depth study of turbulence is best left to other specialised books, a list of which appears in the very rich bibliographic material at the end of the book.

I enjoyed reading this book and will recommend it heartily to my engineering students. But what do I say to those who need to solve a few problems on each chapter to get a more in-depth understanding of the subject, since this book has no problems? Fortunately, I learned that a separate book of solved problems by Marc Fermigier [1] accompanies this book, as it has done for the years it has been used in the Ecole Supérieure de Physique et Chimie Industrielles de Paris.

In summary, this is an excellent book, highly recommended not only for physicists and engineers but also for life scientists, geophysicists, oceanographers, meteorological engineers, and biologists, and it is in general a book that should be at the right hand of all those active or interested in fluid mechanics.

It presents a novel way of studying fluid mechanics and bears very favourable comparison with the distinguished texts in the subject. Reading the book is a joyful experience that stimulates the reader's mind and contributes to the creative observation of the fluid mechanics phenomena in which we live our lives. It should become the standard textbook for senior or graduate courses in fluid mechanics.

Reference

[1] Marc Fermigier, Hydrodynamique physique, Problèmes résolus avec rappels de cours, Dunod, Paris, 1999, 224 pp., 25 Euros.

H. Peerhossaini
Ecole polytechnique de l'Universite de Nantes
CNRS-UMR 6607 Laboratoire de Thermocinetique
B.P. 50609, Rue Christian Pauc
44306 Nantes Cedex 3
France
E-mail address: hassam.peerhossaini@polytech.univ-nantes.fr
Tel.: +33-2-4068-3139; fax: +33-2-4068-3141