AIAA JOURNAL
Vol. 44, No. 12, December 2006

Book Reviews

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Vorticity and Vortex Dynamics

Edited by Jie-Zhi Wu, Hui-Yang Ma, Ming D. Zhou, Springer–Verlag, New York, 2006, 776 pp., $199.00

DOI: 10.2514/1.27462

FLUID mechanics is the science and art of understanding the motion of fluids. These dynamic motions are for the most part rotational or vortical. Scientific observations of vortical flows date back to the days of Da Vinci (1452–1519), but detailed mathematical analyses of vorticity exploring how it is created, evolves, and is destroyed has been made possible only with the celebrated derivations of the Euler equations, by Euler (1707–1783), and the Navier–Stokes equations, by Navier (1785–1836) and Stokes (1819–1903). Although Helmholtz and Kelvin established preliminary laws on vortex motions and circulation in the second half of the 19th century, it is only from the early 20th century that vortical flows have received widespread attention in the fluids community. This led to an improved understanding of vorticity, though many questions are yet to be answered even today. In this book, the authors present a unified view of the dynamics of vorticity in incompressible flows of Newtonian fluids, covering important developments in the field over the last century.

There are a few excellent books already existing in this area. The book by Lugt [1] gives an excellent physical description of mechanisms and diverse applications. The books by Truesdell [2] and Saffman [3] approach the subject elegantly from a theoretical or applied mathematics angle and describe many exact solutions and instability predictions. Interesting pure mathematical aspects, like existence and uniqueness of solutions, finite time singularities, weak solutions, etc., are covered in the monograph of Majda and Bertozzi [4]. The vortex literature was well covered by the preceding books, perhaps with the exceptions of a few topics, like unsteady separation. As such, *Vorticity and Vortex Dynamics* is not filling a big vacuum existing in the literature or a providing a timely publication of some new result. Rather, this book should be considered as an important complement to the preceding books.

Received 23 August 2006; revision received 21 September 2006; accepted for publication 21 September 2006.

The introduction, Chapter 1, gives a short historical review of the progress of the subject. A fuller description of developments would have been more appropriate. Chapter 2 starts by deriving the fundamental continuum laws of fluid motion, the boundary conditions, and the jump conditions at discontinuities. Three classic decompositions, Hodge–Helmholtz, Monge–Clebsch, and Helical–Wave, are discussed next. These are then used to decompose the velocity gradient tensor and the symmetric stress tensor using the Caswell formula for material boundaries, and the generalized Caswell formula for general boundaries. The Biot–Savart law, the Lamb vector, helicity, impulse, enstrophy, and kinetic energy, and their evolution integrals are described in Chapter 3. The presentation of these parts is similar to that of Saffman's [3] book. The Hamiltonian description of fluids and its relation to flows that preserve circulation are briefly described after that. The extremely short description fails to do justice to this vast and important topic. The Lagrangian formulation for viscous fluids is not touched upon. Readers interested in these aspects should refer to the book by Marsden and Ratiu [5]. Chapter 4 is focused on understanding vorticity in prototypical examples, like sphere flows, boundary layers, vortex sheets, etc. Computational methods based on vorticity are also presented, based on the research work of the authors. Although steady separation is a solved problem and easy to understand, unsteady separation is more involved and not well understood, and Chapter 5 addresses these topics. Goldstein's singularity and triple deck theory in steady separation and the Lagrangian unsteady separation theory of Haller are covered.

Exact Navier–Stokes solutions of vortices involving unstrained and strained flows are discussed in Chapter 6. The derivations are done step-by-step and are pleasure to read. A topological dynamical systems view of separation in steady flows is given in Chapter 7. Open and closed separation, fixed point index, and structural stability of topological flow structures, using the Peixoto theorem in dynamical systems theory, are described elegantly. Vortex bubble type flows, flows enclosed by vortex sheets emanating from closed separation are described using the Prandtl–Batchelor theorem in the inviscid limit. Free vortex-layer flows in the steady case and unsteady bluffbody vortex shedding flows which have important applications in vehicular aerodynamics are also presented. A mechanism for vortex formation based on vortex sheet roll-up, and core structure and dynamics are studied in Chapter 8. The presentation on dynamics of curved vortical filaments under the local induction approximation, leading to the nonlinear Schrodinger equation for the curvature evolution, and finite core size approximation, leading to the nonlinear Hirota equation, is nicely done. The dynamics of point vortices and stability of vortex patches are discussed. Important phenomena of vortex–vortex reconnection, interaction of vortex with a no-slip wall, and interaction of a vortex with a shear-free surface are also briefly outlined.

The review of Chapters 9–11 is brief as the material is standard and can be found in many available books focused on these specific topics. Chapter 9 is about the eigenvalue stability analysis of some selected vortices. A description of vortical structures, also called coherent structures, and their instability mechanisms occurring in free shear layers and no-slip boundary layers are described in Chapter 10. The last two chapters, Chapters 11 and 12, are devoted to the study of vorticity based on force and moment calculations on bodies moving in fluid flow and dynamic potential vorticity aspects in geophysical flows under the quasi-geostrophic approximation, respectively.

Although the book covers an array of topics related to vorticity, there are still whole arrays of topics that can be included here. Addition of these topics would make this a more complete and well-rounded book in this field. The reviewer understands that the book is already lengthy and the inclusion of these topics may be too ambitious a goal. As can be expected, some of these topics are more involved and some are even ongoing topics of research. The book does not address topics in compressible flows, especially those involving interaction of shocks, interfaces, and acceleration, like Richtmeyer–Meshkov and Rayleigh–Taylor instabilities, etc. A more in-depth coverage of geophysical and atmospheric flows would have been appropriate. The fascinating dynamics of the vorticity field in cases of non-Newtonian fluid flows, magnetohydrodynamic flows, reacting flows, and detonations are also not addressed. The applications of vortex dynamics in cosmology and superfluid Helium 2, though a bit far from the scope and authors' interest, would be wonderful additions to read. The entire areas of biological and medical applications are also not touched upon. The lack of coverage of these topics does not in any way diminish the outstanding quality of this work. These comments should be simply viewed as possible additions to the work and convey to the reader the richness and vastness of possible applications of vortex dynamics.

The overall organization and writing style of the book is good and the authors make their best effort to present the material in a systematic and coherent fashion, so that readers can grasp the concepts quickly. This book will be 1) an excellent source of material for selected topics in graduate classes on fluid mechanics, 2) a good book for an advanced graduate class on vortex dynamics, and 3) a nice reference book for fluid mechanicians, practicing engineers, and scientists. For undergraduate students well trained in applied mathematical techniques, chapters in this book can also be used as part of junior and senior level undergraduate fluids classes. Though the book is self-contained in presentation and can be read standalone by a mature reader, a better and more full appreciation of the subject and how it fits into the rest of fluid mechanics encompassing other aspects can be gotten by using this book in conjunction with other classic books on the subject of mechanics of fluids, such as Lamb [6], Milne-Thomson [7], Landau and Lifshitz [8], and Batchelor [9].

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