Preface

Vortical flows are flows with *vortices* as their skeleton structures. Vortices are seen everywhere in our universe and on the earth: from spiral galaxies, atmospheric and oceanic circulations to hurricanes and typhoons, tornadoes to bath stub vortices; from volcanoes' erupted smoke rings and mushroom clouds of nuclear explosions to vortex rings ejected from the mouth of dolphin and smoker, or formed in a heart downstream of the mitral valve that separates the left atrium and left ventricle; from tip vortices of aircraft, rotor blade, and turbo fan to complicated ring-like structures in the wake of birds, insects and fishes; from well organized laminar vortices to coherent turbulent structures.

This book provides a systematic introduction to the physical theory of vortical flows at graduate level. It grew from our monograph *Vorticity and Vortex Dynamics* (Springer 2006), but has been thoroughly rewritten. Some advanced topics in the monograph have been removed, and more basic topics have been added. Recent advances since 2006 in the field of fundamental interest are included. Nevertheless, two basic characteristics of the monograph are inherited and further enhanced, which make both the monograph and the present book differ from other existing books on the subject:

(1) We consider the theory of vortical flows as a branch of fluid dynamics focusing on *shearing process* in fluid motion, measured by *vorticity*. A vortex is defined as a fluid body with high vorticity concentration. The evolution of vorticity field is governed by *vorticity dynamics*. Coexisting with this process is the compression–expansion process (*compressing process* for short) measured by dilatation, pressure, or other thermodynamic variables, of which the main structure is shock waves where *entropy process* is naturally involved. The three fundamental processes in fluid motion are coupled with each other both inside the flow field and at solid boundary. We believe that only on the basis of this broad background can the physics of vortical flows be fully understood.

(2) We study vortical flows according to their natural evolution stages, from being generated to dissipated. As preparation, the first three chapters of the book provide background knowledge for entering vortical flows. Due to the coupling of shearing process with other processes, this knowledge appears wider and more

profound than common books on vortical flows. Chapter 1 reviews standard fundamental kinematics and dynamics of generic viscous and compressible flow, including some elementary results of process identification and decomposition. The whole of Chap. 2 is devoted to the basic theory of fundamental processes in fluid motion, their splitting and coupling. Chapter 3 discusses general theory and physics of vorticity dynamics. Although later chapters will be mainly confined to incompressible flow, Chaps. 1–3 cover much broader materials with a hope to facilitate future exploration of more complicated compressible vortical flows.

The rest of the book deals with vortices and vortical flows. Of various vortices the primary form is *layer-like vortices* or *shear layers*, and secondary but stronger form is *axial vortices* mainly formed by the rolling up of shear layers. Thus, Chap. 4 is on attached shear layer (namely *boundary layer*) and free shear layers. As Reynolds number approaches infinity, these layers become asymptotically attached and free vortex sheets, which are the subject of Chap. 5. This chapter ends with vortex-sheet rolling up and initial formation of axial vortices, so it is naturally followed by Chaps. 6 and 7 on typical solutions of columnar vortices and vortex rings, respectively. Chapter 8 studies flow separation first, which is a key localized dynamic process turning a simple attached flow to complex, namely to become global separated flow with concentrated vortices that is studied next. Chapter 9 is an introduction to total force and moment acting to a body moving through the fluid, in terms of various vortical structures.

Chapters 10 and 11 discuss the instability and breakdown of axial vortices, and vortical structures in transitional and turbulent shear flows, respectively. Both chapters require some elementary knowledge of flow instability and turbulence, which are placed (somewhat artificially) in the beginnings of Chaps. 10 and 11, respectively. Finally, A general theory of vector and tensor field is presented in the Appendix for readers' convenience.

Problems are given at the end of each chapter and Appendix, some for helping to understand the basic theories, and some involving specific applications; but the emphasis of both is always on physical thinking. Problems with asterisk may need more effort.

The reader of this book is assumed to have learned undergraduate fluid mechanics or aerodynamics in majors of mechanics, aerospace and mechanical engineering, and be familiar with physics, advanced calculus and differential equations. Better background of these fields will make it easier to understand the present book. Most part of the book materials has been used as Lecture Notes and were taught by J.Z. at Peking University over the past 15 years as a one-semester graduate course of advanced fluid dynamics. The course has been proved acceptable by most students with warm and inspiring feedback.

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