CHAPTER 1

Introduction

Fluid dynamics concerns fluid motions. No single book, or even shelf of books, could hope to describe the full range of known fluid dynamics. By tradition, introductory books mainly concern three simplified categories of flow:

(1) *Gasdynamics* – compressible frictionless flows.
(2) *Viscous flows*, *boundary layers*, and *turbulence* – incompressible frictional flows.
(3) *Potential flows* – irrotational frictionless flows.

Books with generic titles like *fluid dynamics*, *fluid mechanics*, or *aerodynamics* generally survey all three basic categories of flow. Other books concern just gasdynamics or just viscous flows. These books sacrifice breadth for depth. Given the huge differences between compressible inviscid flows and viscous incompressible flows, single-topic treatments make sense for many readers, who need to know only one or the other.

Computational fluids dynamics (*CFD*) concerns computer simulations of fluid flows. Each type of fluid flow listed above has inspired a myriad of competing numerical methods, each with its own pros and cons, each demanding a good understanding of both traditional fluid dynamics and numerical analysis. As a result, the size of computational fluid dynamics far exceeds that of traditional fluid dynamics. At the present time, most CFD books survey numerical methods for all three of the basic flow categories. While such surveys work well for traditional fluid dynamics, the larger size of CFD requires more compromises and trade-offs. With so much to cover, even a two-volume survey can only describe the basic principles and techniques common to all three categories of flows, plus a limited and sometimes arbitrary sampling of the principles and techniques specific to each category of flow. Such condensation forces the reader to consult the original research literature for most of the details on most of the methods for each type of flow. But the expurgated surveys found in most CFD books do not provide enough background to face the typically complicated and highly mathematical CFD research papers.

This book takes a different approach – it focuses entirely on gasdynamics, and a limited type of gasdynamics at that. It omits computational methods for compressible potential flows. It omits computational methods for chemically reacting flows, real gas flows, and other important advanced topics. Instead, this book deals nearly exclusively with compressible, inviscid, unsteady flows of perfect gases. This approximately describes many flows of practical interest, especially aerodynamic flows. Furthermore, such flows serve as important *model problems* for, and constitute an essential first step towards, a broader range of practical compressible flows, including viscous and real gas flows. In keeping with the model problem concept, most of the book concerns one-dimensional flows; the last chapter explains how one-dimensional concepts carry over directly to multidimensions. The book also spends a lot of time discussing *scalar conservation laws*, such as Burgers' equation, which have precious few real-world applications, and whose popularity derives almost entirely from their success as model problems. Although a focus on model problems requires more patience early on, this author knows of no better or faster way to learn today's CFD.

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This book does not claim to prepare readers to write state-of-the-art CFD codes. Writing CFD codes requires years of study, reading several books and dozens if not hundreds of research papers, preferably under the tutelage of a CFD expert. However, given the widespread availability of excellent commercial software and freeware, such as the RAMPANT code from the Fluent Corporation, most readers will never need to do large amounts of CFD coding. This book tries to prepare its readers to understand the CFD literature, or at least major chunks of it, should that become necessary. Also this book also tries to give its readers much of the background needed to intelligently evaluate and use the available CFD software.

Now let's look at the basic roadmap. The book has five parts. The first part reviews gasdynamics. The second part reviews numerical analysis. The third describes the basic principles of computational gasdynamics, including conservation, stability, upwinding, artificial viscosity, and so forth. The fourth part covers the *first-generation methods* of computational gasdynamics, also known as *nonadaptive* methods, including Lax–Wendroff methods, the Lax–Friedrichs method, and first-order upwind methods. The fifth part describes *second-* and *third-generation* methods of computational gasdynamics, also known as *adaptive* or *solution-sensitive* methods, including TVD, ENO, MUSCL, PPM, flux-corrected, and flux-limited methods. So fasten your seatbelts and prepare for a long lonesome ride across the heartland of CFD.