PREFACE

BACKGROUND

Fluid mechanics is an exciting and fascinating subject with unlimited practical applications ranging from microscopic biological systems to automobiles, airplanes, and spacecraft propulsion. Fluid mechanics has also historically been one of the most challenging subjects for undergraduate students because proper analysis of fluid mechanics problems requires not only knowledge of the concepts but also physical intuition and experience. Our hope is that this book, through its careful explanations of concepts and its use of numerous practical examples, sketches, figures, and photographs, bridges the gap between knowledge and the proper application of that knowledge.

Fluid mechanics is a mature subject; the basic equations and approximations are well established and can be found in any introductory textbook. Our book is distinguished from other introductory books because we present the subject in a *progressive order* from simple to more difficult, building each chapter upon foundations laid down in earlier chapters. We provide more diagrams and photographs that other books because fluid mechanics, is by its nature, a highly visual subject. Only by illustrating the concepts discussed, can students fully appreciate the mathematical significance of the material.

OBJECTIVES

This book has been written for the first fluid mechanics course for undergraduate engineering students. There is sufficient material for a two-course sequence, if desired. We assume that readers will have an adequate background in calculus, physics, engineering mechanics, and thermodynamics. The objectives of this text are

- To present the *basic principles and equations* of fluid mechanics.
- To show numerous and diverse real-world *engineering examples* to give the student the intuition necessary for correct application of fluid mechanics principles in engineering applications.
- To develop an *intuitive understanding* of fluid mechanics by emphasizing the physics, and reinforcing that understanding through illustrative figures and photographs.

The book contains enough material to allow considerable flexibility in teaching the course. Aeronautics and aerospace engineers might emphasize potential flow, drag and lift, compressible flow, turbomachinery, and CFD, while mechanical or civil engineering instructors might choose to emphasize pipe flows and open-channel flows, respectively.

NEW TO THE THIRD EDITION

In this edition, the overall content and order of presentation has not changed significantly except for the following: the visual impact of all figures and photographs has been enhanced by a full color treatment. We also added new photographs throughout the book, often replacing existing diagrams with photographs in order to convey the practical real-life applications of the material. Several new Application Spotlights have been added to the end of selected chapters. These introduce students to industrial applications and exciting research projects being conducted by leaders in the field about material presented in the chapter. We hope these motivate students to see the relevance and application of the materials they are studying. New sections on Biofluids have been added to Chapters 8 and 9, written by guest author Keefe Manning of The Pennsylvania State University, along with bio-related examples and homework problems in those chapters.

New solved example problems were added to some chapters and several new end-of-chapter problems or modifications to existing problems were made to make them more versatile and practical. Most significant is the addition of Fundamentals of Engineering (FE) exam-type problems to help students prepare to take their Professional Engineering exams. Finally, the end-of-chapter problems that require Computational Fluid Dynamics (CFD) have been moved to the text website (www.mheducation.asia/olc/cengel) where updates based on software or operating system changes can be better managed.

PHILOSOPHY AND GOAL

The Third Edition of *Fluid Mechanics: Fundamentals and Applications* has the same goals and philosophy as the other texts by lead author Yunus Çengel.

- Communicates directly with tomorrow's engineers in a *simple yet precise* manner
- Leads students toward a clear understanding and firm grasp of the *basic principles* of fluid mechanics
- Encourages creative thinking and development of a *deeper understanding* and *intuitive feel* for fluid mechanics
- Is read by students with *interest* and *enthusiasm* rather than merely as a guide to solve homework problems

The best way to learn is by practice. Special effort is made throughout the book to reinforce the material that was presented earlier (in each chapter as well as in material from previous chapters). Many of the illustrated example problems and end-of-chapter problems are comprehensive and encourage students to review and revisit concepts and intuitions gained previously.

Throughout the book, we show examples generated by computational fluid dynamics (CFD). We also provide an introductory chapter on the subject. Our goal is not to teach the details about numerical algorithms associated with CFD—this is more properly presented in a separate course. Rather, our intent is to introduce undergraduate students to the capabilities and limitations of CFD as an *engineering tool*. We use CFD solutions in much the same way as experimental results are used from wind tunnel tests (i.e., to reinforce understanding of the physics of fluid flows and to provide quality flow visualizations that help explain fluid behavior). With dozens of CFD end-of-chapter problems posted on the website, instructors have ample opportunity to introduce the basics of CFD throughout the course.

CONTENT AND ORGANIZATION

This book is organized into 15 chapters beginning with fundamental concepts of fluids, fluid properties, and fluid flows and ending with an introduction to computational fluid dynamics.

- Chapter 1 provides a basic introduction to fluids, classifications of fluid flow, control volume versus system formulations, dimensions, units, significant digits, and problem-solving techniques.
- Chapter 2 is devoted to fluid properties such as density, vapor pressure, specific heats, speed of sound, viscosity, and surface tension.
- Chapter 3 deals with fluid statics and pressure, including manometers and barometers, hydrostatic forces on submerged surfaces, buoyancy and stability, and fluids in rigid-body motion.
- Chapter 4 covers topics related to fluid kinematics, such as the differences between Lagrangian and Eulerian descriptions of fluid flows, flow patterns, flow visualization, vorticity and rotationality, and the Reynolds transport theorem.
- Chapter 5 introduces the fundamental conservation laws of mass, momentum, and energy, with emphasis on the proper use of the mass, Bernoulli, and energy equations and the engineering applications of these equations.
- Chapter 6 applies the Reynolds transport theorem to linear momentum and angular momentum and emphasizes practical engineering applications of finite control volume momentum analysis.
- Chapter 7 reinforces the concept of dimensional homogeneity and introduces the Buckingham Pi theorem of dimensional analysis, dynamic similarity, and the method of repeating variables—material that is useful throughout the rest of the book and in many disciplines in science and engineering.
- Chapter 8 is devoted to flow in pipes and ducts. We discuss the differences between laminar and turbulent flow, friction losses in pipes and ducts, and minor losses in piping networks. We also explain how to properly select a pump or fan to match a piping network. Finally, we discuss various experimental devices that are used to measure flow rate and velocity, and provide a brief introduction to biofluid mechanics.
- Chapter 9 deals with differential analysis of fluid flow and includes derivation and application of the continuity equation, the Cauchy equation, and the Navier-Stokes equation. We also introduce the stream function and describe its usefulness in analysis of fluid flows, and we provide a brief introduction to biofluids. Finally, we point out some of the unique aspects of differential analysis related to biofluid mechanics.
- Chapter 10 discusses several *approximations* of the Navier–Stokes equation and provides example solutions for each approximation, including creeping flow, inviscid flow, irrotational (potential) flow, and boundary layers.
- Chapter 11 covers forces on bodies (drag and lift), explaining the distinction between friction and pressure drag, and providing drag

coefficients for many common geometries. This chapter emphasizes the practical application of wind tunnel measurements coupled with dynamic similarity and dimensional analysis concepts introduced earlier in Chapter 7.

- Chapter 12 extends fluid flow analysis to compressible flow, where the behavior of gases is greatly affected by the Mach number. In this chapter, the concepts of expansion waves, normal and oblique shock waves, and choked flow are introduced.
- Chapter 13 deals with open-channel flow and some of the unique features associated with the flow of liquids with a free surface, such as surface waves and hydraulic jumps.
- Chapter 14 examines turbomachinery in more detail, including pumps, fans, and turbines. An emphasis is placed on how pumps and turbines work, rather than on their detailed design. We also discuss overall pump and turbine design, based on dynamic similarity laws and simplified velocity vector analyses.
- Chapter 15 describes the fundamental concepts of computational fluid dyamics (CFD) and shows students how to use commercial CFD codes as tools to solve complex fluid mechanics problems. We emphasize the *application* of CFD rather than the algorithms used in CFD codes.

Each chapter contains a wealth of end-of-chapter homework problems. A comprehensive set of appendix is provided, giving the thermodynamic and fluid properties of several materials, in addition to air and water, along with some useful plots and tables. Many of the end-of-chapter problems require the use of material properties from the appendices to enhance the realism of the problems.

LEARNING TOOLS

EMPHASIS ON PHYSICS

A distinctive feature of this book is its emphasis on the physical aspects of the subject matter in addition to mathematical representations and manipulations. The authors believe that the emphasis in undergraduate education should remain on *developing a sense of underlying physical mechanisms* and a *mastery of solving practical problems* that an engineer is likely to face in the real world. Developing an intuitive understanding should also make the course a more motivating and worthwhile experience for the students.

EFFECTIVE USE OF ASSOCIATION

An observant mind should have no difficulty understanding engineering sciences. After all, the principles of engineering sciences are based on our *everyday experiences* and *experimental observations*. Therefore, a physical, intuitive approach is used throughout this text. Frequently, *parallels are drawn* between the subject matter and students' everyday experiences so that they can relate the subject matter to what they already know.

SELF-INSTRUCTING

The material in the text is introduced at a level that an average student can follow comfortably. It speaks *to* students, not *over* students. In fact, it is *self-instructive*. Noting that the principles of science are based on experimental observations, most of the derivations in this text are largely based on physical arguments, and thus they are easy to follow and understand.

EXTENSIVE USE OF ARTWORK AND PHOTOGRAPHS

Figures are important learning tools that help the students "get the picture," and the text makes effective use of graphics. It contains more figures, photographs, and illustrations than any other book in this category. Figures attract attention and stimulate curiosity and interest. Most of the figures in this text are intended to serve as a means of emphasizing some key concepts that would otherwise go unnoticed; some serve as page summaries.

CONSISTENT COLOR SCHEME FOR FIGURES

The figures have a consistent color scheme applied for all arrows.

- Blue: (⟶) motion related, like velocity vectors
- Green: (⟶) force and pressure related, and torque
- Black: (⟶) distance related arrows and dimensions
- Red: (⟶) energy related, like heat and work
- Purple: (⟶) acceleration and gravity vectors, vorticity, and miscellaneous

NUMEROUS WORKED-OUT EXAMPLES

All chapters contain numerous worked-out *examples* that both clarify the material and illustrate the use of basic principles in a context that helps develops the student's intuition. An *intuitive* and *systematic* approach is used in the solution of all example problems. The solution methodology starts with a statement of the problem, and all objectives are identified. The assumptions and approximations are then stated together with their justifications. Any properties needed to solve the problem are listed separately. Numerical values are used together with numbers to emphasize that without units, numbers are meaningless. The significance of each example's result is discussed following the solution. This methodical approach is also followed and provided in the solutions to the end-of-chapter problems, available to instructors.

A WEALTH OF REALISTIC END-OF-CHAPTER PROBLEMS

The end-of-chapter problems are grouped under specific topics to make problem selection easier for both instructors and students. Within each group of problems are *Concept Questions,* indicated by "C," to check the students' level of understanding of basic concepts. Problems under *Fundamentals of Engineering (FE) Exam Problems* are designed to help students prepare for the *Fundamentals of Engineering* exam, as they prepare for their Professional Engineering license. The problems under *Review Problems* are more comprehensive in nature and are not directly tied to any specific section of a chapter—in some cases they require review of material learned in previous chapters. Problems designated as *Design and Essay* are intended to encourage students to make engineering judgments, to conduct independent exploration of topics of interest, and to communicate their findings in a professional manner. Problems with the icon are solved using EES, and complete solutions together with parametric studies are included the text website. Problems with the icon are comprehensive in nature and are intended to be solved with a computer, preferably using the EES software. Several economics- and safety-related problems are incorporated throughout to enhance cost and safety awareness among engineering students. Answers to selected problems are listed immediately following the problem for convenience to students.

USE OF COMMON NOTATION

The use of different notation for the same quantities in different engineering courses has long been a source of discontent and confusion. A student taking both fluid mechanics and heat transfer, for example, has to use the notation Q for volume flow rate in one course, and for heat transfer in the other. The need to unify notation in engineering education has often been raised, even in some reports of conferences sponsored by the National Science Foundation through Foundation Coalitions, but little effort has been made to date in this regard. For example, refer to the final report of the *Mini-Conference on Energy Stem Innovations*, May 28 and 29, 2003, University of Wisconsin. In this text we made a conscious effort to minimize this conflict by adopting the familiar thermodynamic notation $\dot{V}$ for volume flow rate, thus reserving the notation Q for heat transfer. Also, we consistently use an overdot to denote time rate. We think that both students and instructors will appreciate this effort to promote a common notation.

COMBINED COVERAGE OF BERNOULLI AND ENERGY EQUATIONS

The Bernoulli equation is one of the most frequently used equations in fluid mechanics, but it is also one of the most misused. Therefore, it is important to emphasize the limitations on the use of this idealized equation and to show how to properly account for imperfections and irreversible losses. In Chapter 5, we do this by introducing the energy equation right after the Bernoulli equation and demonstrating how the solutions of many practical engineering problems differ from those obtained using the Bernoulli equation. This helps students develop a realistic view of the Bernoulli equation.

A SEPARATE CHAPTER ON CFD

Commercial *Computational Fluid Dynamics* (CFD) codes are widely used in engineering practice in the design and analysis of flow systems, and it has become exceedingly important for engineers to have a solid understanding of the fundamental aspects, capabilities, and limitations of CFD. Recognizing that most undergraduate engineering curriculums do not have room for a full course on CFD, a separate chapter is included here to make up for this deficiency and to equip students with an adequate background on the strengths and weaknesses of CFD.

APPLICATION SPOTLIGHTS

Throughout the book are highlighted examples called *Application Spotlights* where a real-world application of fluid mechanics is shown. A unique feature of these special examples is that they are written by *guest authors*. The Application Spotlights are designed to show students how fluid mechanics has diverse applications in a wide variety of fields. They also include eye-catching photographs from the guest authors' research.

GLOSSARY OF FLUID MECHANICS TERMS

Throughout the chapters, when an important key term or concept is introduced and defined, it appears in **black** boldface type. Fundamental fluid mechanics terms and concepts appear in **red** boldface type, and these fundamental terms also appear in a comprehensive end-of-book glossary developed by Professor James Brasseur of The Pennsylvania State University. This unique glossary is an excellent learning and review tool for students as they move forward in their study of fluid mechanics. In addition, students can test their knowledge of these fundamental terms by using the interactive flash cards and other resources located on our accompanying website (www.mheducation.asia/olc/cengel).

CONVERSION FACTORS

Frequently used conversion factors, physical constants, and properties of air and water at 20°C and atmospheric pressure are listed on the front inner cover pages of the text for easy reference.

NOMENCLATURE

A list of the major symbols, subscripts, and superscripts used in the text are listed on the inside back cover pages of the text for easy reference.

SUPPLEMENTS

These supplements are available to adopters of the book:

Text Website

Web support is provided for the book on the text specific website at www.mheducation.asia/olc/cengel. Visit this robust site for book and supplement information, errata, author information, and further resources for instructors and students.

Engineering Equation Solver (EES)

Developed by Sanford Klein and William Beckman from the University of Wisconsin–Madison, this software combines equation-solving capability and engineering property data. EES can do optimization, parametric analysis, and linear and nonlinear regression, and provides publication-quality plotting capabilities. Thermodynamics and transport properties for air, water, and many other fluids are built-in and EES allows the user to enter property data or functional relationships.