### McGRAW-HILL SERIES IN MECHANICAL ENGINEERING

<table>
<thead>
<tr>
<th>Authors/Editors</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alciatore and Histand</td>
<td><em>Introduction to Mechatronics and Measurement Systems</em></td>
</tr>
<tr>
<td>Anderson</td>
<td><em>Computational Fluid Dynamics: The Basics with Applications</em></td>
</tr>
<tr>
<td>Anderson</td>
<td><em>Fundamentals of Aerodynamics</em></td>
</tr>
<tr>
<td>Anderson</td>
<td><em>Introduction to Flight</em></td>
</tr>
<tr>
<td>Anderson</td>
<td><em>Modern Compressible Flow</em></td>
</tr>
<tr>
<td>Barber</td>
<td><em>Intermediate Mechanics of Materials</em></td>
</tr>
<tr>
<td>Beer/Johnston</td>
<td><em>Vector Mechanics for Engineers</em></td>
</tr>
<tr>
<td>Beer/Johnston/DeWolf</td>
<td><em>Mechanics of Materials</em></td>
</tr>
<tr>
<td>Borman and Ragland</td>
<td><em>Combustion Engineering</em></td>
</tr>
<tr>
<td>Budynas</td>
<td><em>Advanced Strength and Applied Stress Analysis</em></td>
</tr>
<tr>
<td>Çengel and Boles</td>
<td><em>Thermodynamics: An Engineering Approach</em></td>
</tr>
<tr>
<td>Çengel and Cimbala</td>
<td><em>Fluid Mechanics: Fundamentals and Applications</em></td>
</tr>
<tr>
<td>Çengel and Turner</td>
<td><em>Fundamentals of Thermal-Fluid Sciences</em></td>
</tr>
<tr>
<td>Çengel</td>
<td><em>Heat Transfer: A Practical Approach</em></td>
</tr>
<tr>
<td>Crespo da Silva</td>
<td><em>Intermediate Dynamics</em></td>
</tr>
<tr>
<td>Dieter</td>
<td><em>Engineering Design: A Materials &amp; Processing Approach</em></td>
</tr>
<tr>
<td>Dieter</td>
<td><em>Mechanical Metallurgy</em></td>
</tr>
<tr>
<td>Doebelin</td>
<td><em>Measurement Systems: Application &amp; Design</em></td>
</tr>
<tr>
<td>Dunn</td>
<td><em>Measurement &amp; Data Analysis for Engineering &amp; Science</em></td>
</tr>
<tr>
<td>EDS, Inc.</td>
<td><em>I-DEAS Student Guide</em></td>
</tr>
<tr>
<td>Hamrock/Jacobson/Schmid</td>
<td><em>Fundamentals of Machine Elements</em></td>
</tr>
<tr>
<td>Henkel and Pense</td>
<td><em>Structure and Properties of Engineering Material</em></td>
</tr>
<tr>
<td>Heywood</td>
<td><em>Internal Combustion Engine Fundamentals</em></td>
</tr>
<tr>
<td>Holman</td>
<td><em>Experimental Methods for Engineers</em></td>
</tr>
<tr>
<td>Holman</td>
<td><em>Heat Transfer</em></td>
</tr>
<tr>
<td>Hsu</td>
<td><em>MEMS &amp; Microsystems: Manufacture &amp; Design</em></td>
</tr>
<tr>
<td>Hutton</td>
<td><em>Fundamentals of Finite Element Analysis</em></td>
</tr>
<tr>
<td>Kays/Crawford/Weigand</td>
<td><em>Convective Heat and Mass Transfer</em></td>
</tr>
<tr>
<td>Kelly</td>
<td><em>Fundamentals of Mechanical Vibrations</em></td>
</tr>
<tr>
<td>Kreider/Rabl/Curtiss</td>
<td><em>The Heating and Cooling of Buildings</em></td>
</tr>
<tr>
<td>Mattingly</td>
<td><em>Elements of Gas Turbine Propulsion</em></td>
</tr>
<tr>
<td>Meirovitch</td>
<td><em>Fundamentals of Vibrations</em></td>
</tr>
<tr>
<td>Norton</td>
<td><em>Design of Machinery</em></td>
</tr>
<tr>
<td>Palm</td>
<td><em>System Dynamics</em></td>
</tr>
<tr>
<td>Reddy</td>
<td><em>An Introduction to Finite Element Method</em></td>
</tr>
<tr>
<td>Ribando</td>
<td><em>Heat Transfer Tools</em></td>
</tr>
<tr>
<td>Schaffer et al.</td>
<td><em>The Science and Design of Engineering Materials</em></td>
</tr>
<tr>
<td>Schey</td>
<td><em>Introduction to Manufacturing Processes</em></td>
</tr>
<tr>
<td>Schlachting</td>
<td><em>Boundary-Layer Theory</em></td>
</tr>
<tr>
<td>Shames</td>
<td><em>Mechanics of Fluids</em></td>
</tr>
<tr>
<td>Shigley/Mischke/Budynas</td>
<td><em>Mechanical Engineering Design</em></td>
</tr>
<tr>
<td>Smith</td>
<td><em>Foundations of Materials Science and Engineering</em></td>
</tr>
<tr>
<td>Stoecker</td>
<td><em>Design of Thermal Systems</em></td>
</tr>
<tr>
<td>Suryanarayana and Arici</td>
<td><em>Design and Simulation of Thermal Systems</em></td>
</tr>
<tr>
<td>Turns</td>
<td><em>An Introduction to Combustion: Concepts and Applications</em></td>
</tr>
<tr>
<td>Ugural</td>
<td><em>Stresses in Plates and Shells</em></td>
</tr>
<tr>
<td>Ugural</td>
<td><em>Mechanical Design: An Integrated Approach</em></td>
</tr>
<tr>
<td>Ullman</td>
<td><em>The Mechanical Design Process</em></td>
</tr>
<tr>
<td>Wark and Richards</td>
<td><em>Thermodynamics</em></td>
</tr>
<tr>
<td>White</td>
<td><em>Fluid Mechanics</em></td>
</tr>
<tr>
<td>White</td>
<td><em>Viscous Fluid Flow</em></td>
</tr>
<tr>
<td>Zeid</td>
<td><em>Mastering CAD/CAM</em></td>
</tr>
</tbody>
</table>
Dedication

To all students—In hopes of enhancing your desire and enthusiasm to explore the inner workings of our marvelous universe, of which fluid mechanics is a small but fascinating part; our hope is that this book enhances your love of learning, not only about fluid mechanics, but about life.
Yunus A. Çengel is Professor Emeritus of Mechanical Engineering at the University of Nevada, Reno. He received his B.S. in mechanical engineering from Istanbul Technical University and his M.S. and Ph.D. in mechanical engineering from North Carolina State University. His research areas are renewable energy, desalination, exergy analysis, heat transfer enhancement, radiation heat transfer, and energy conservation. He served as the director of the Industrial Assessment Center (IAC) at the University of Nevada, Reno, from 1996 to 2000. He has led teams of engineering students to numerous manufacturing facilities in Northern Nevada and California to do industrial assessments, and has prepared energy conservation, waste minimization, and productivity enhancement reports for them.


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Dr. Cimbala is the coauthor of the textbook *Indoor Air Quality Engineering: Environmental Health and Control of Indoor Pollutants* (2003), published by Marcel-Dekker, Inc. He has also contributed to parts of other books, and is the author or co-author of dozens of journal and conference papers. More information can be found at www.mne.psu.edu/cimbala.

Professor Cimbala is the recipient of several outstanding teaching awards and views his book writing as an extension of his love of teaching. He is a member of the American Institute of Aeronautics and Astronautics (AIAA), the American Society of Mechanical Engineers (ASME), the American Society for Engineering Education (ASEE), and the American Physical Society (APS).
# Brief Contents

<table>
<thead>
<tr>
<th>Chapter One</th>
<th>Introduction and Basic Concepts</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter Two</td>
<td>Properties of Fluids</td>
<td>35</td>
</tr>
<tr>
<td>Chapter Three</td>
<td>Pressure and Fluid Statics</td>
<td>65</td>
</tr>
<tr>
<td>Chapter Four</td>
<td>Fluid Kinematics</td>
<td>121</td>
</tr>
<tr>
<td>Chapter Five</td>
<td>Mass, Bernoulli, and Energy Equations</td>
<td>171</td>
</tr>
<tr>
<td>Chapter Six</td>
<td>Momentum Analysis of Flow Systems</td>
<td>227</td>
</tr>
<tr>
<td>Chapter Seven</td>
<td>Dimensional Analysis and Modeling</td>
<td>269</td>
</tr>
<tr>
<td>Chapter Eight</td>
<td>Flow in Pipes</td>
<td>321</td>
</tr>
<tr>
<td>Chapter Nine</td>
<td>Differential Analysis of Fluid Flow</td>
<td>399</td>
</tr>
<tr>
<td>Chapter Ten</td>
<td>Approximate Solutions of the Navier–Stokes Equation</td>
<td>471</td>
</tr>
<tr>
<td>Chapter Eleven</td>
<td>Flow Over Bodies: Drag and Lift</td>
<td>561</td>
</tr>
<tr>
<td>Chapter Twelve</td>
<td>Compressible Flow</td>
<td>611</td>
</tr>
<tr>
<td>Chapter Thirteen</td>
<td>Open-Channel Flow</td>
<td>679</td>
</tr>
<tr>
<td>Chapter Fourteen</td>
<td>Turbomachinery</td>
<td>735</td>
</tr>
<tr>
<td>Chapter Fifteen</td>
<td>Introduction to Computational Fluid Dynamics</td>
<td>817</td>
</tr>
</tbody>
</table>
CONTENTS

Preface xv

CHAPTER ONE
INTRODUCTION AND BASIC CONCEPTS 1

1–1 Introduction 2
What Is a Fluid? 2
Application Areas of Fluid Mechanics 4

1–2 The No-Slip Condition 6

1–3 A Brief History of Fluid Mechanics 7

1–4 Classification of Fluid Flows 9
Viscous versus Inviscid Regions of Flow 9
Internal versus External Flow 10
Compressible versus Incompressible Flow 10
Laminar versus Turbulent Flow 11
Natural (or Unforced) versus Forced Flow 11
Steady versus Unsteady Flow 11
One-, Two-, and Three-Dimensional Flows 12

1–5 System and Control Volume 14

1–6 Importance of Dimensions and Units 15
Some SI and English Units 16
Dimensional Homogeneity 18
Unity Conversion Ratios 20

1–7 Mathematical Modeling of Engineering Problems 21
Modeling in Engineering 21

1–8 Problem-Solving Technique 22
Step 1: Problem Statement 22
Step 2: Schematic 23
Step 3: Assumptions and Approximations 23
Step 4: Physical Laws 23
Step 5: Properties 23
Step 6: Calculations 23
Step 7: Reasoning, Verification, and Discussion 23

1–9 Engineering Software Packages 24
Engineering Equation Solver (EES) 25
FLUENT 26

1–10 Accuracy, Precision, and Significant Digits 26

Application Spotlight: What Nuclear Blasts and Raindrops Have in Common 31
Summary 30
References and Suggested Reading 30
Problems 32

CHAPTER TWO
PROPERTIES OF FLUIDS 35

2–1 Introduction 36
Continuum 36

2–2 Density and Specific Gravity 37
Density of Ideal Gases 38

2–3 Vapor Pressure and Cavitation 39

2–4 Energy and Specific Heats 41

2–5 Coefficient of Compressibility 42
Coefficient of Volume Expansion 44

2–6 Viscosity 46

2–7 Surface Tension and Capillary Effect 51

Summary 55
References and Suggested Reading 56
Application Spotlight: Cavitation 57
Problems 58

CHAPTER THREE
PRESSURE AND FLUID STATICS 65

3–1 Pressure 66
Pressure at a Point 67
Variation of Pressure with Depth 68

3–2 The Manometer 71
Other Pressure Measurement Devices 74

3–3 The Barometer and Atmospheric Pressure 75

3–4 Introduction to Fluid Statics 78
CONTENTS

3–5 Hydrostatic Forces on Submerged Plane Surfaces 79
   Special Case: Submerged Rectangular Plate 82
3–6 Hydrostatic Forces on Submerged Curved Surfaces 85
3–7 Buoyancy and Stability 89
   Stability of Immersed and Floating Bodies 92
3–8 Fluids in Rigid-Body Motion 95
   Special Case 1: Fluids at Rest 96
   Special Case 2: Free Fall of a Fluid Body 97
   Acceleration on a Straight Path 97
   Rotation in a Cylindrical Container 99
   Summary 102
   References and Suggested Reading 103
   Problems 103

CHAPTER FOUR
FLUID KINEMATICS 121

4–1 Lagrangian and Eulerian Descriptions 122
   Acceleration Field 124
   Material Derivative 127
4–2 Fundamentals of Flow Visualization 129
   Streamlines and Streamtubes 129
   Pathlines 130
   Streaklines 132
   Timelines 134
   Refractive Flow Visualization Techniques 135
   Surface Flow Visualization Techniques 136
4–3 Plots of Fluid Flow Data 136
   Profile Plots 137
   Vector Plots 137
   Contour Plots 138
4–4 Other Kinematic Descriptions 139
   Types of Motion or Deformation of Fluid Elements 139
   Vorticity and Rotationality 144
   Comparison of Two Circu lar Flows 147
4–5 The Reynolds Transport Theorem 148
   Alternate Derivation of the Reynolds Transport Theorem 153
   Relationship between Material Derivative and RTT 155
   Application Spotlight: Fluidic Actuators 157
   Summary 156
   References and Suggested Reading 158
   Problems 158

CHAPTER FIVE
MASS, BERNOULLI, AND ENERGY EQUATIONS 171

5–1 Introduction 172
   Conservation of Mass 172
   Conservation of Momentum 172
   Conservation of Energy 172
5–2 Conservation of Mass 173
   Mass and Volume Flow Rates 173
   Conservation of Mass Principle 175
   Moving or Deforming Control Volumes 177
   Mass Balance for Steady-Flow Processes 177
   Special Case: Incompressible Flow 178
5–3 Mechanical Energy and Efficiency 180
5–4 The Bernoulli Equation 185
   Acceleration of a Fluid Particle 186
   Derivation of the Bernoulli Equation 186
   Force Balance across Streamlines 188
   Unsteady, Compressible Flow 189
   Static, Dynamic, and Stagnation Pressures 189
   Limitations on the Use of the Bernoulli Equation 190
   Hydraulic Grade Line (HGL) and Energy Grade Line (EGL) 192
5–5 Applications of the Bernoulli Equation 194
5–6 General Energy Equation 201
   Energy Transfer by Heat, \( Q \) 202
   Energy Transfer by Work, \( W \) 202
5–7 Energy Analysis of Steady Flows 206
   Special Case: Incompressible Flow with No Mechanical Work
   Devices and Negligible Friction 208
   Kinetic Energy Correction Factor, \( \alpha \) 208
   Summary 215
   References and Suggested Reading 216
   Problems 216

CHAPTER SIX
MOMENTUM ANALYSIS OF FLOW SYSTEMS 227

6–1 Newton’s Laws and Conservation of Momentum 228
6–2 Choosing a Control Volume 229
6–3 Forces Acting on a Control Volume 230
6–4  The Linear Momentum Equation  233
   Special Cases  235
   Momentum-Flux Correction Factor, β  235
   Steady Flow  238
   Steady Flow with One Inlet and One Outlet  238
   Flow with No External Forces  238
6–5  Review of Rotational Motion and Angular
   Momentum  248
6–6  The Angular Momentum Equation  250
   Special Cases  252
   Flow with No External Moments  253
   Radial-Flow Devices  254
   Summary  259
   References and Suggested Reading  259
   Problems  260

Chapter Seven
Dimensional Analysis and Modeling  269
7–1  Dimensions and Units  270
7–2  Dimensional Homogeneity  271
   Nondimensionalization of Equations  272
7–3  Dimensional Analysis and Similarity  277
7–4  The Method of Repeating Variables and the
   Buckingham Pi Theorem  281
   Historical Spotlight: Persons Honored by
   Nondimensional Parameters  289
7–5  Experimental Testing and Incomplete
   Similarity  297
   Setup of an Experiment and Correlation of Experimental
   Data  297
   Incomplete Similarity  298
   Wind Tunnel Testing  298
   Flows with Free Surfaces  301
   Application Spotlight: How a Fly Flies  304
   Summary  305
   References and Suggested Reading  305
   Problems  306

Chapter Eight
Flow in Pipes  321
8–1  Introduction  322
8–2  Laminar and Turbulent Flows  323
   Reynolds Number  324
8–3  The Entrance Region  325
   Entry Lengths  326
8–4  Laminar Flow in Pipes  327
   Pressure Drop and Head Loss  329
   Inclined Pipes  331
   Laminar Flow in Noncircular Pipes  332
8–5  Turbulent Flow in Pipes  335
   Turbulent Shear Stress  336
   Turbulent Velocity Profile  338
   The Moody Chart  340
   Types of Fluid Flow Problems  343
8–6  Minor Losses  347
8–7  Piping Networks and Pump Selection  354
   Piping Systems with Pumps and Turbines  356
8–8  Flow Rate and Velocity Measurement  364
   Pitot and Pitot-Static Probes  365
   Obstruction Flowmeters: Orifice, Venturi, and Nozzle
   Meters  366
   Positive Displacement Flowmeters  369
   Turbine Flowmeters  370
   Variable-Area Flowmeters (Rotameters)  372
   Ultrasonic Flowmeters  373
   Electromagnetic Flowmeters  375
   Vortex Flowmeters  376
   Thermal (Hot-Wire and Hot-Film) Anemometers  377
   Laser Doppler Velocimetry  378
   Particle Image Velocimetry  380
   Application Spotlight: How Orifice Plate
   Flowmeters Work, or Do Not Work  383
   Summary  384
   References and Suggested Reading  385
   Problems  386

Chapter Nine
Differential Analysis of Fluid Flow  399
9–1  Introduction  400
9–2  Conservation of Mass—The Continuity
   Equation  400
   Derivation Using the Divergence Theorem  401
   Derivation Using an Infinitesimal Control Volume  402
   Alternative Form of the Continuity Equation  405
   Continuity Equation in Cylindrical Coordinates  406
   Special Cases of the Continuity Equation  406
9–3  The Stream Function  412
   The Stream Function in Cartesian Coordinates  412
   The Stream Function in Cylindrical Coordinates  419
   The Compressible Stream Function  420
12–4 Isentropic Flow through Nozzles 624
Converging Nozzles 625
Converging–Diverging Nozzles 629

12–5 Shock Waves and Expansion Waves 633
Normal Shocks 633
Oblique Shocks 640
Prandtl–Meyer Expansion Waves 644

12–6 Duct Flow with Heat Transfer and Negligible Friction (Rayleigh Flow) 648
Property Relations for Rayleigh Flow 654
Choked Rayleigh Flow 655

12–7 Adiabatic Duct Flow with Friction (Fanno Flow) 657
Property Relations for Fanno Flow 660
Choked Fanno Flow 663

Application Spotlight: Shock-Wave/Boundary-Layer Interactions 667

Summary 668
References and Suggested Reading 669
Problems 670

CHAPTER THIRTEEN
OPEN-CHANNEL FLOW 679

13–1 Classification of Open-Channel Flows 680
Uniform and Varied Flows 680
Laminar and Turbulent Flows in Channels 681

13–2 Froude Number and Wave Speed 683
Speed of Surface Waves 685

13–3 Specific Energy 687

13–4 Continuity and Energy Equations 690

13–5 Uniform Flow in Channels 691
Critical Uniform Flow 693
Superposition Method for Nonuniform Perimeters 693

13–6 Best Hydraulic Cross Sections 697
Rectangular Channels 699
Trapezoidal Channels 699

13–7 Gradually Varied Flow 701
Liquid Surface Profiles in Open Channels, y(x) 703
Some Representative Surface Profiles 706
Numerical Solution of Surface Profile 708

13–8 Rapidly Varied Flow and Hydraulic Jump 709

13–9 Flow Control and Measurement 714
Underflow Gates 714
Overflow Gates 716

Summary 723
References and Suggested Reading 724
Problems 725

CHAPTER FOURTEEN
TURBOMACHINERY 735

14–1 Classifications and Terminology 736

14–2 Pumps 738
Pump Performance Curves and Matching a Pump to a Piping System 739
Pump Cavitation and Net Positive Suction Head 745
Pumps in Series and Parallel 748
Positive-Displacement Pumps 751
Dynamic Pumps 754
Centrifugal Pumps 754
Axial Pumps 764

14–3 Pump Scaling Laws 773
Dimensional Analysis 773
Pump Specific Speed 775
Affinity Laws 777

14–4 Turbines 781
Positive-Displacement Turbines 782
Dynamic Turbines 782
Impulse Turbines 783
Reaction Turbines 785

14–5 Turbine Scaling Laws 795
Dimensionless Turbine Parameters 795
Turbine Specific Speed 797
Gas and Steam Turbines 800

Application Spotlight: Rotary Fuel Atomizers 802

Summary 803
References and Suggested Reading 803
Problems 804

CHAPTER FIFTEEN
INTRODUCTION TO COMPUTATIONAL FLUID DYNAMICS 817

15–1 Introduction and Fundamentals 818
Motivation 818
Equations of Motion 818
Solution Procedure 819
Additional Equations of Motion 821
Grid Generation and Grid Independence 821
Boundary Conditions 826
Practice Makes Perfect 830
15–2 Laminar CFD Calculations 831
   Pipe Flow Entrance Region at Re = 500 831
   Flow around a Circular Cylinder at Re = 150 833
15–3 Turbulent CFD Calculations 840
   Flow around a Circular Cylinder at Re = 10,000 843
   Flow around a Circular Cylinder at Re = 107 844
   Design of the Stator for a Vane-Axial Flow Fan 845
15–4 CFD with Heat Transfer 853
   Temperature Rise through a Cross-Flow Heat Exchanger 853
   Cooling of an Array of Integrated Circuit Chips 855
15–5 Compressible Flow CFD Calculations 860
   Compressible Flow through a Converging–Diverging Nozzle 861
   Oblique Shocks over a Wedge 865
15–6 Open-Channel Flow CFD Calculations 866
   Flow over a Bump on the Bottom of a Channel 867
   Flow through a Sluice Gate (Hydraulic Jump) 868
   Application Spotlight: A Virtual Stomach 869
   Summary 870
   References and Suggested Reading 870
   Problems 871

APPENDIX 1
PROPERTY TABLES AND CHARTS (SI UNITS) 885

TABLE A–1 Molar Mass, Gas Constant, and Ideal-Gas Specific Heats of Some Substances 886
TABLE A–2 Boiling and Freezing Point Properties 887
TABLE A–3 Properties of Saturated Water 888
TABLE A–4 Properties of Saturated Refrigerant-134a 889
TABLE A–5 Properties of Saturated Ammonia 890
TABLE A–6 Properties of Saturated Propane 891
TABLE A–7 Properties of Liquids 892
TABLE A–8 Properties of Liquid Metals 893
TABLE A–9 Properties of Air at 1 atm Pressure 894
TABLE A–10 Properties of Gases at 1 atm Pressure 895

TABLE A–11 Properties of the Atmosphere at High Altitude 897
FIGURE A–12 The Moody Chart for the Friction Factor for Fully Developed Flow in Circular Pipes 898
TABLE A–13 One-dimensional isentropic compressible flow functions for an ideal gas with \( k = 1.4 \) 899
TABLE A–14 One-dimensional normal shock functions for an ideal gas with \( k = 1.4 \) 900
TABLE A–15 Rayleigh flow functions for an ideal gas with \( k = 1.4 \) 901
TABLE A–16 Fanno flow functions for an ideal gas with \( k = 1.4 \) 902

APPENDIX 2
PROPERTY TABLES AND CHARTS (ENGLISH UNITS) 903

TABLE A–1E Molar Mass, Gas Constant, and Ideal-Gas Specific Heats of Some Substances 904
TABLE A–2E Boiling and Freezing Point Properties 905
TABLE A–3E Properties of Saturated Water 906
TABLE A–4E Properties of Saturated Refrigerant-134a 907
TABLE A–5E Properties of Saturated Ammonia 908
TABLE A–6E Properties of Saturated Propane 909
TABLE A–7E Properties of Liquids 910
TABLE A–8E Properties of Liquid Metals 911
TABLE A–9E Properties of Air at 1 atm Pressure 912
TABLE A–10E Properties of Gases at 1 atm Pressure 913
TABLE A–11E Properties of the Atmosphere at High Altitude 915

Glossary 917
Index 931
BACKGROUND
Fluid mechanics is an exciting and fascinating subject with unlimited practical applications ranging from microscopic biological systems to automobiles, airplanes, and spacecraft propulsion. Yet fluid mechanics has historically been one of the most challenging subjects for undergraduate students. Unlike earlier freshman- and sophomore-level subjects such as physics, chemistry, and engineering mechanics, where students often learn equations and then “plug and chug” on their calculators, proper analysis of a problem in fluid mechanics requires much more. Oftentimes, students must first assess the problem, make and justify assumptions and/or approximations, apply the relevant physical laws in their proper forms, and solve the resulting equations before ever plugging any numbers into their calculators. Many problems in fluid mechanics require more than just knowledge of the subject, 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 proper application of that knowledge.

Fluid mechanics is a mature subject; the basic equations and approximations are well established and can be found in numerous introductory fluid mechanics books. The books are distinguished from one another in the way the material is presented. An accessible fluid mechanics book should present the material in a progressive order from simple to more difficult, building each chapter upon foundations laid down in previous chapters. In this way, even the traditionally challenging aspects of fluid mechanics can be learned effectively. Fluid mechanics is by its very nature a highly visual subject, and students learn more readily by visual stimulation. It is therefore imperative that a good fluid mechanics book also provide quality figures, photographs, and visual aids that help to explain the significance and meaning of the mathematical expressions.

OBJECTIVES
This book is intended for use as a textbook in the first fluid mechanics course for undergraduate engineering students in their junior or senior year. Students are assumed to have an adequate background in calculus, physics, engineering mechanics, and thermodynamics. The objectives of this text are

- To cover the basic principles and equations of fluid mechanics
- To present numerous and diverse real-world engineering examples to give students a feel for how fluid mechanics is applied in engineering practice
- To develop an intuitive understanding of fluid mechanics by emphasizing the physics, and by supplying attractive figures and visual aids to reinforce the physics
The text contains sufficient material to give instructors flexibility as to which topics to emphasize. For example, aeronautics and aerospace engineering instructors may emphasize potential flow, drag and lift, compressible flow, turbomachinery, and CFD, while mechanical and civil engineering instructors may choose to emphasize pipe flows and open-channel flows, respectively. The book has been written with enough breadth of coverage that it can be used for a two-course sequence in fluid mechanics if desired.

PHILOSOPHY AND GOAL
We have adopted the same philosophy as that of the texts Thermodynamics: An Engineering Approach by Y. A. Çengel and M. A. Boles, Heat Transfer: A Practical Approach by Y. A. Çengel, and Fundamentals of Thermal-Fluid Sciences by Y. A. Çengel and R. H. Turner, all published by McGraw-Hill. Namely, our goal is to offer an engineering textbook that

- Communicates directly to the minds of 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 an aid to solve problems

It is our philosophy that the best way to learn is by practice. Therefore, special effort is made throughout the book to reinforce material that was presented earlier (both earlier in the chapter and in previous chapters). For example, many of the illustrated example problems and end-of-chapter problems are comprehensive, forcing the student to review concepts learned in previous chapters.

Throughout the book, we show examples generated by computational fluid dynamics (CFD), and we provide an introductory chapter on CFD. Our goal is not to teach details about numerical algorithms associated with CFD—this is more properly presented in a separate course, typically at the graduate level. Rather, it is our intent 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 we use experimental results from a wind tunnel test, i.e., to reinforce understanding of the physics of fluid flows and to provide quality flow visualizations that help to explain fluid behavior.

CONTENT AND ORGANIZATION
This book is organized into 15 chapters beginning with fundamental concepts of fluids and fluid flows and ending with an introduction to computational fluid dynamics, the application of which is rapidly becoming more commonplace, even at the undergraduate level.

- 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, 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 the 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.
• 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.
• Chapter 10 discusses several approximations of the Navier–Stokes equations 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, and 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 dynamics (CFD) and shows students how to use commercial CFD codes as a tool to solve complex fluid mechanics problems. We emphasize the application of CFD rather than the algorithms used in CFD codes.

Each chapter contains a large number of end-of-chapter homework problems suitable for use by instructors. Most of the problems that involve calculations are in SI units, but approximately 20 percent are written in English units. Finally, a comprehensive set of appendices is provided, giving the thermodynamic and fluid properties of several materials, not just air and water as in most introductory fluids texts. Many of the end-of-chapter problems require use of the properties found in these appendices.

**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**
Figures are important learning tools that help the students “get the picture,” and the text makes effective use of graphics. It contains more figures 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.
CHAPTER OPENERS AND SUMMARIES
Each chapter begins with an overview of the material to be covered. A summary is included at the end of each chapter, providing a quick review of basic concepts and important relations, and pointing out the relevance of the material.

NUMEROUS WORKED-OUT EXAMPLES
WITH A SYSTEMATIC SOLUTIONS PROCEDURE
Each chapter contains several worked-out examples that clarify the material and illustrate the use of the basic principles. An intuitive and systematic approach is used in the solution of the example problems, while maintaining an informal conversational style. The problem is first stated, and the objectives are identified. The assumptions are then stated, together with their justifications. The properties needed to solve the problem are listed separately. Numerical values are used together with their units to emphasize that numbers without units are meaningless, and unit manipulations are as important as manipulating the numerical values with a calculator. The significance of the findings is discussed following the solutions. This approach is also used consistently in the solutions presented in the instructor’s solutions manual.

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. 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 designated by an “E” are in English units, and SI users can ignore them. Problems with the are solved using EES, and complete solutions together with parametric studies are included on the enclosed DVD. Problems with the are comprehensive in nature and are intended to be solved with a computer, preferably using the EES software that accompanies this text. 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.

A CHOICE OF SI ALONE OR SI/ENGLISH UNITS
In recognition of the fact that English units are still widely used in some industries, both SI and English units are used in this text, with an emphasis on SI. The material in this text can be covered using combined SI/English units or SI units alone, depending on the preference of the instructor. The property tables and charts in the appendices are presented in both units, except the ones that involve dimensionless quantities. Problems, tables, and charts in English units are designated by “E” after the number for easy recognition, and they can be ignored easily by the SI users.

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 blue 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.mhhe.com/cengel).

CONVERSION FACTORS
Frequently used conversion factors, physical constants, and frequently used 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:

STUDENT RESOURCES DVD
Packaged free with every new copy of the text, this DVD provides a wealth of resources for students including Fluid Mechanics Videos, a CFD Animations Library, and EES Software.

ONLINE LEARNING CENTER
Web support is provided for the book on our Online Learning Center at www.mhhe.com/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.

FLUENT FLOWLAB® SOFTWARE AND TEMPLATES
As an integral part of Chapter 15, “Introduction to Computational Fluid Dynamics,” we provide access to a student-friendly CFD software package developed by Fluent Inc. In addition, we provide over 40 FLUENT FLOWLAB templates to complement the end-of-chapter problems in Chapter 15. These problems and templates are unique in that they are designed with both a fluid mechanics learning objective and a CFD learning objective in mind.

INSTRUCTOR’S RESOURCE CD-ROM (AVAILABLE TO INSTRUCTORS ONLY)
This CD, available to instructors only, offers a wide range of classroom preparation and presentation resources including an electronic solutions manual with PDF files by chapter, all text chapters and appendices as downloadable PDF files, and all text figures in JPEG format.
**COSMOS CD-ROM**  
(AVAILABLE TO INSTRUCTORS ONLY)  
This CD, available to instructors only, provides electronic solutions delivered via our database management tool. McGraw-Hill’s COSMOS allows instructors to streamline the creation of assignments, quizzes, and tests by using problems and solutions from the textbook—as well as their own custom material.

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