

Contents

Preface xi

Chapter 1

Introduction 3

- 1.1 Preliminary Remarks 3
- 1.2 History and Scope of Fluid Mechanics 4
- 1.3 Problem-Solving Techniques 6
- 1.4 The Concept of a Fluid 6
- 1.5 The Fluid as a Continuum 8
- 1.6 Dimensions and Units 9
- 1.7 Properties of the Velocity Field 17
- 1.8 Thermodynamic Properties of a Fluid 18
- 1.9 Viscosity and Other Secondary Properties 25
- 1.10 Basic Flow Analysis Techniques 40
- 1.11 Flow Patterns: Streamlines, Streaklines, and Pathlines 41
- 1.12 The Engineering Equation Solver 46
- 1.13 Uncertainty in Experimental Data 46
- 1.14 The Fundamentals of Engineering (FE) Examination 48
 - Problems 49
 - Fundamentals of Engineering Exam Problems 57
 - Comprehensive Problems 58
 - References 61

Chapter 2

Pressure Distribution in a Fluid 65

- 2.1 Pressure and Pressure Gradient 65
- 2.2 Equilibrium of a Fluid Element 67
- 2.3 Hydrostatic Pressure Distributions 68
- 2.4 Application to Manometry 75

- 2.5 Hydrostatic Forces on Plane Surfaces 78
- 2.6 Hydrostatic Forces on Curved Surfaces 86
- 2.7 Hydrostatic Forces in Layered Fluids 89
- 2.8 Buoyancy and Stability 91
- 2.9 Pressure Distribution in Rigid-Body Motion 97
- 2.10 Pressure Measurement 105
 - Summary 109
 - Problems 109
 - Word Problems 132
 - Fundamentals of Engineering Exam Problems 133
 - Comprehensive Problems 134
 - Design Projects 135
 - References 136

Chapter 3

Integral Relations for a Control Volume 139

- 3.1 Basic Physical Laws of Fluid Mechanics 139
- 3.2 The Reynolds Transport Theorem 143
- 3.3 Conservation of Mass 150
- 3.4 The Linear Momentum Equation 155
- 3.5 Frictionless Flow: The Bernoulli Equation 169
- 3.6 The Angular Momentum Theorem 178
- 3.7 The Energy Equation 184
 - Summary 195
 - Problems 195
 - Word Problems 224
 - Fundamentals of Engineering Exam Problems 224
 - Comprehensive Problems 226
 - Design Project 227
 - References 227

Chapter 4**Differential Relations for Fluid Flow 229**

- 4.1 The Acceleration Field of a Fluid 230
- 4.2 The Differential Equation of Mass Conservation 232
- 4.3 The Differential Equation of Linear Momentum 238
- 4.4 The Differential Equation of Angular Momentum 244
- 4.5 The Differential Equation of Energy 246
- 4.6 Boundary Conditions for the Basic Equations 249
- 4.7 The Stream Function 253
- 4.8 Vorticity and Irrotationality 261
- 4.9 Frictionless Irrotational Flows 263
- 4.10 Some Illustrative Incompressible Viscous Flows 268
 - Summary 276
 - Problems 277
 - Word Problems 288
 - Fundamentals of Engineering Exam Problems 288
 - Comprehensive Problems 289
 - References 290

Chapter 5**Dimensional Analysis and Similarity 293**

- 5.1 Introduction 298
- 5.2 The Principle of Dimensional Homogeneity 296
- 5.3 The Pi Theorem 302
- 5.4 Nondimensionalization of the Basic Equations 312
- 5.5 Modeling and Its Pitfalls 321
 - Summary 333
 - Problems 333
 - Word Problems 342
 - Fundamentals of Engineering Exam Problems 342
 - Comprehensive Problems 343
 - Design Projects 344
 - References 344

Chapter 6**Viscous Flow in Ducts 347**

- 6.1 Reynolds Number Regimes 347
- 6.2 Internal versus External Viscous Flow 352
- 6.3 Head Loss—The Friction Factor 355
- 6.4 Laminar Fully Developed Pipe Flow 357
- 6.5 Turbulence Modeling 359

- 6.6 Turbulent Pipe Flow 365
- 6.7 Four Types of Pipe Flow Problems 373
- 6.8 Flow in Noncircular Ducts 379
- 6.9 Minor or Local Losses in Pipe Systems 388
- 6.10 Multiple-Pipe Systems 397
- 6.11 Experimental Duct Flows: Diffuser Performance 403
- 6.12 Fluid Meters 408
 - Summary 429
 - Problems 430
 - Word Problems 448
 - Fundamentals of Engineering Exam Problems 449
 - Comprehensive Problems 450
 - Design Projects 452
 - References 453

Chapter 7**Flow Past Immersed Bodies 457**

- 7.1 Reynolds Number and Geometry Effects 457
- 7.2 Momentum Integral Estimates 461
- 7.3 The Boundary Layer Equations 464
- 7.4 The Flat-Plate Boundary Layer 467
- 7.5 Boundary Layers with Pressure Gradient 476
- 7.6 Experimental External Flows 482
 - Summary 509
 - Problems 510
 - Word Problems 523
 - Fundamentals of Engineering Exam Problems 524
 - Comprehensive Problems 524
 - Design Project 525
 - References 526

Chapter 8**Potential Flow and Computational Fluid Dynamics 529**

- 8.1 Introduction and Review 529
- 8.2 Elementary Plane Flow Solutions 532
- 8.3 Superposition of Plane Flow Solutions 539
- 8.4 Plane Flow Past Closed-Body Shapes 545
- 8.5 Other Plane Potential Flows 555
- 8.6 Images 559
- 8.7 Airfoil Theory 562
- 8.8 Axisymmetric Potential Flow 574
- 8.9 Numerical Analysis 579

- Summary 593
- Problems 594
- Word Problems 604
- Comprehensive Problems 605
- Design Projects 606
- References 606

Chapter 9**Compressible Flow 609**

- 9.1 Introduction: Review of Thermodynamics 609
- 9.2 The Speed of Sound 614
- 9.3 Adiabatic and Isentropic Steady Flow 616
- 9.4 Isentropic Flow with Area Changes 622
- 9.5 The Normal Shock Wave 629
- 9.6 Operation of Converging and Diverging Nozzles 637
- 9.7 Compressible Duct Flow with Friction 642
- 9.8 Frictionless Duct Flow with Heat Transfer 654
- 9.9 Two-Dimensional Supersonic Flow 659
- 9.10 Prandtl-Meyer Expansion Waves 669
 - Summary 681
 - Problems 682
 - Word Problems 695
 - Fundamentals of Engineering Exam Problems 696
 - Comprehensive Problems 696
 - Design Projects 698
 - References 698

Chapter 10**Open-Channel Flow 701**

- 10.1 Introduction 701
- 10.2 Uniform Flow: The Chézy Formula 707
- 10.3 Efficient Uniform-Flow Channels 712
- 10.4 Specific Energy: Critical Depth 714
- 10.5 The Hydraulic Jump 722
- 10.6 Gradually Varied Flow 726

- 10.7 Flow Measurement and Control by Weirs 734
 - Summary 741
 - Problems 741
 - Word Problems 754
 - Fundamentals of Engineering Exam Problems 754
 - Comprehensive Problems 754
 - Design Projects 756
 - References 756

Chapter 11**Turbomachinery 759**

- 11.1 Introduction and Classification 759
- 11.2 The Centrifugal Pump 762
- 11.3 Pump Performance Curves and Similarity Rules 768
- 11.4 Mixed- and Axial-Flow Pumps: The Specific Speed 778
- 11.5 Matching Pumps to System Characteristics 785
- 11.6 Turbines 793
 - Summary 807
 - Problems 807
 - Word Problems 820
 - Comprehensive Problems 820
 - Design Project 822
 - References 822

Appendix A Physical Properties of Fluids 824**Appendix B Compressible Flow Tables 829****Appendix C Conversion Factors 836****Appendix D Equations of Motion in Cylindrical Coordinates 838****Answers to Selected Problems 840****Index 847**