Contents

Preface **xi**

Chapter 1
Introduction 3

1.1 Preliminary Remarks 3
1.2 The Concept of a Fluid 4
1.3 The Fluid as a Continuum 6
1.4 Dimensions and Units 7
1.5 Properties of the Velocity Field 14
1.6 Thermodynamic Properties of a Fluid 16
1.7 Viscosity and Other Secondary Properties 22
1.8 Basic Flow-Analysis Techniques 35
1.9 Flow Patterns: Streamlines, Streaklines, and Pathlines 37
1.10 The Engineering Equation Solver 41
1.11 Uncertainty of Experimental Data 42
1.12 The Fundamentals of Engineering (FE) Examination 43
1.13 Problem-Solving Techniques 44
1.14 History and Scope of Fluid Mechanics 44
Problems 46
Fundamentals of Engineering Exam Problems 53
Comprehensive Problems 54
References 55

Chapter 2
Pressure Distribution **in a Fluid 59**

2.1 Pressure and Pressure Gradient 59
2.2 Equilibrium of a Fluid Element 61
2.3 Hydrostatic Pressure Distributions 63
2.4 Application to Manometry 70
2.5 Hydrostatic Forces on Plane Surfaces 74
2.6 Hydrostatic Forces on Curved Surfaces 79
2.7 Hydrostatic Forces in Layered Fluids 82
2.8 Buoyancy and Stability 84
2.9 Pressure Distribution in Rigid-Body Motion 89
2.10 Pressure Measurement 97
Summary 100
Problems 102
Word Problems 125
Fundamentals of Engineering Exam Problems 125
Comprehensive Problems 126
Design Projects 127
Roferenccs 127

Chapter 3
Integral Relations for a Control Volume 129

3.1 Basic Physical Laws of Fluid Mechanics 129
3.2 The Reynolds Transport Theorem 133
3.3 Conservation of Mass 141
3.4 The Linear Momentum Equation 146
3.5 The Angular-Momentum Theorem 158
3.6 The Energy Equation 163
3.7 Frictionless Flow: The Bernoulli Equation 174
Summary 183
Problems 184
Word Problems 210
Fundamentals of Engineering Exam Problems 210
Comprehensive Problems 211
Design Project 212
References 213

Chapter 4
Differential Relations for a Fluid Particle 2 15

4.1 The Acceleration Field of a Fluid 215
4.2 The Differential Equation of Mass Conservation 217
4.3 The Differential Equation of Linear Momentum 223
4.4 The Differential Equation of Angular Momentum 230
4.5 The Differential Equation of Energy 23 1
4.6 Boundary Conditions for the Basic Equations 234
4.7 The Stream Function 238
4.8 Vorticity and Irrotationality 245
4.9 Frictionless Irrotational Flows 247
4.10 Some Illustrative Plane Potential Flows 252
4.11 Some Illustration s Incompressible Viscous Flows 258
Summary 263
Problems 264
Word Problems 273
Fundamentals of Engineering Exam Problems 273
Comprehensive Applied Problem 274
References 275

Chapter 5
Dimensional Analysis and Similarity 277

5.1 Introduction 277
5.2 The Principle of Dimensional Homogeneity 280
5.3 The Pi Theorem 286
5.4 Nondimensionalization of the Basic Equations 292
5.5 Modeling and Its Pitfalls 301
Summary 311
Problems 3 11
Word Problems 3 18
Fundamentals of Engineering Exam Problems 3 19
Comprehensive Problems 3 19
Design Projects 320
References 321

Chapter 6
Viscous Flow in Ducts 325

6.1 Reynolds-Number Regimes 325
6.2 Internal versus External Viscous Flows 330
6.3 Semiempirical Turbulent Shear Correlations 333
6.4 Flow in a Circular Pipe 338
6.5 Three Types of Pipe-Flow Problems 351
6.6 Flow in Noncircular Ducts 357
6.7 Minor Losses in Pipe Systems 367
6.8 Multiple-Pipe Systems 375
6.9 Experimental Duct Flows: Diffuser Performance 381
6.10 Fluid Meters 385
Summary 404
Problems 405
Word Problems 420
Fundamentals of Engineering Exam Problems 420
Comprehensive Problems 421
Design Projects 422
References 423

Chapter 7
Flow Past Immersed Bodies 427

7.1 Reynolds-Number and Geometry Effects 427
7.2 Momentum-Integral Estimates 43 1
7.3 The Boundary-Layer Equations 434
7.4 The Flat-Plate Boundary Layer 436
7.5 Boundary Layers with Pressure Grardient 445
7.6 Experimental External Flows 451
Summary 476
Problems 476
Word Problems 489
Fundamentals of Engineering Exam Problems 489
Comprehensive Problems 490
Design Project 491
References 491

Chapter 8
Potential Flow and Computational Fluid Dynamics 495

8.1 Introduction and Review 495
8.2 Elementary Plane-Flow Solutions 498
8.3 Superposition of Plane-Flow Solutions 500
8.4 Plane Flow Past Closed-Body Shapes 507
8.5 Other Plane Potential Flows 5 16
8.6 Images 521
8.7 Airfoil Theory 523
8.8 Axisymmetric Potential Flow 534
8.9 Numerical Analysis 540
summary 555

Problems 555
Word Problems 566
Comprehensive Problems 566
Design Projects 567
References 567

Chapter 9
Compressible Flow 571

9.1 Introduction 571
9.2 The Speed of Sound 575
9.3 Adiabatic and Isentropic Steady Flow 578
9.4 Isentropic Flow with Area Changes 583
9.5 The Normal-Shock Wave 590
9.6 Operation of Converging and Diverging Nozzles 598
9.7 Compressible Duct Flow with Friction 603
9.8 Frictionless Duct Flow with Heat Transfer 613
9.9 Two-Dimensional Supersonic Flow 618
9.10 Prandtl-Meyer Expansion Waves 628
Summary 640
Problems 641
Word Problems 653
Fundamentals of Engineering Exam Problems 653
Comprehensive Problems 654
Design Projects 654
References 655

Chapter 10
Open-Channel Flow 659

10.1 Introduction 659
10.2 Uniform Flow; the Chézy Formula 664
10.3 Efficient Uniform-Flow Channels 669
10.4 Specific Energy; Critical Depth 671
10.5 The Hydraulic Jump 678
10.6 Gradually Varied Flow 682
10.7 Flow Measurement and Control by Weirs 687
Summary 695
Problems 695
Word Problems 706
Fundamentals of Engineering Exam Problems 707
Comprehensive Problems 707
Design Projects 707
References 708

Chapter 11
Turbomachinery 711

11.1 Introduction and Classification 711
11.2 The Centrifugal Pump 714
11.3 Pump Performance Curves and Similarity Rules 720
11.4 Mixed- and Axial-Flow Pumps: The Specific Speed 729
11.5 Matching Pumps to System Characteristics 735
11.6 Turbines 742
Summary 755
Problems 755
Word Problems 765
Comprehensive Problems 766
Design Project 767
References 767

Appendix A Physical Properties of Fluids 769

Appendix B Compressible-Flow Tables 774

Appendix C Conversion Factors 791

Appendix D Equations of Motion in Cylindrical Coordinates 793

Appendix E Introduction to EES 795

Answers to Selected Problems 806

Index 813