Contents

Preface xv
List of Symbols xix
List of Abbreviations xxv

Chapter 1 Introduction 1

1.1 Scope of Fluid Mechanics 1
1.2 Historical Sketch of the Development of Fluid Mechanics 2
1.3 The Book, Its Contents, and How to Best Study Fluid Mechanics 3
1.4 Approach to Problem Solving 4
1.5 Dimensions and Units 6

Chapter 2 Properties of Fluids 13

2.1 Distinction Between a Solid and a Fluid 13
2.2 Distinction Between a Gas and a Liquid 13
2.3 Density, Specific Weight, Specific Volume, and Specific Gravity 14
2.4 Compressible and Incompressible Fluids 16
2.5 Compressibility of Liquids 17
2.6 Specific Weight of Liquids 19
2.7 Property Relations for Perfect Gases 22
2.8 Compressibility of Perfect Gases 25
2.9 Standard Atmosphere 27
2.10 Ideal Fluid 29
2.11 Viscosity 29
2.12 Surface Tension 37
2.13 Vapor Pressure of Liquids 40
Problems 41

Chapter 3 Fluid Statics 45

3.1 Pressure at a Point the Same in All Directions 45
3.2 Variation of Pressure in a Static Fluid 46
3.3 Pressure Expressed in Height of Fluid 50
3.4 Absolute and Gage Pressures 53
3.5 Measurement of Pressure 55
3.6 Force on a Plane Area 66
3.7 Center of Pressure 68
3.8 Force on a Curved Surface 77
3.9 Buoyancy and Stability of Submerged and Floating Bodies 81
3.10 Liquid Masses Subjected to Acceleration 88
Problems 92

Chapter 4 Basics of Fluid Flow 97

4.1 Types of Flow 97
4.2 Laminar and Turbulent Flow 98
4.3 Steady Flow and Uniform Flow 101
4.4 Path Lines, Streamlines, and Streak Lines 102
4.5 Flow Rate and Mean Velocity 103
4.6 Fluid System and Control Volume 106
4.7 Equation of Continuity 108
4.8 One-, Two-, and Three-Dimensional Flow 110
4.9 The Flow Net 111
4.10 Use and Limitations of the Flow Net 114
4.11 Frame of Reference in Flow Problems 117
4.12 Velocity and Acceleration in Steady Flow 117
4.13 Velocity and Acceleration in Unsteady Flow 121
Problems 124

Chapter 5 Energy in Steady Flow 127

5.1 Energies of a Flowing Fluid 127
5.2 Equation for Steady Motion of an Ideal Fluid Along a Streamline, and Bernoulli's Theorem 131
5.3 Equation for Steady Motion of a Real Fluid Along a Streamline 135
5.4 Pressure in Fluid Flow 138
5.5 General Energy Equation for Steady Flow of Any Fluid 140
5.6 Energy Equations for Steady Flow of Incompressible Fluids, Bernoulli's Theorem 143
5.7 Energy Equation for Steady Flow of Compressible Fluids 147
5.8 Head 150
5.9 Power Considerations in Fluid Flow 150
5.10 Cavitation 154
5.11 Definition of Hydraulic Grade Line and Energy Line 158
5.12 Loss of Head at Submerged Discharge 160
5.13 Application of Hydraulic Grade Line and Energy Line 161
5.14 Method of Solution of Liquid Flow Problems 165
5.15 Jet Trajectory 169
5.16 Flow in a Curved Path 172
5.17 Forced or Rotational Vortex 173
5.18 Free or Irrotational Vortex 176

Problems 179

Chapter 6 Momentum and Forces in Fluid Flow 185

6.1 Development of the Momentum Principle 185
6.2 Navier-Stokes Equations 188
6.3 Momentum Correction Factor 189
6.4 Applications of the Momentum Principle 190
6.5 Force on Pressure Conduits 193
6.6 Force of a Free Jet on a Stationary Vane or Blade 198
6.7 Moving Vanes: Relation Between Absolute and Relative Velocities 200
6.8 Force of a Jet on One or More Moving Vanes or Blades 201
6.9 Reaction of a Jet 206
6.10 Jet Propulsion 210
6.11 Rotating Machines: Continuity, Relative Velocities, Torque 212
6.12 Head Equivalent of Mechanical Work 219
6.13 Flow Through a Rotating Channel 219
6.14 Reaction with Rotation 220
6.15 Momentum Principle Applied to Propellers and Windmills 222

Problems 226

Chapter 7 Similitude and Dimensional Analysis 232

7.1 Definition and Uses of Similitude 232
7.2 Geometric Similarity 232
7.3 Kinematic Similarity 233
7.4 Dynamic Similarity 234
7.5 Scale Ratios 241
7.6 Comments on Models 243
7.7 Dimensional Analysis 245

Problems 252

Chapter 8 Steady Incompressible Flow in Pressure Conduits 255

8.1 Laminar and Turbulent Flow 255
8.2 Critical Reynolds Number 256
8.3 Hydraulic Radius, Hydraulic Diameter 258
8.4 Friction Head Loss in Conduits of Constant Cross Section 258
8.5 Friction in Circular Conduits 261
8.6 Friction in Noncircular Conduits 263
8.7 Laminar Flow in Circular Pipes 264
8.8 Entrance Conditions in Laminar Flow 265
8.9 Turbulent Flow 268
8.10 Viscous Sublayer in Turbulent Flow 271

8.11 Velocity Profile in Turbulent Flow 276
8.12 Pipe Roughness 280
8.13 Chart for Friction Factor 282
8.14 Single-Pipe Flow: Solution Basics 285
8.15 Single-Pipe Flow: Solution by Trials 287
8.16 Single-Pipe Flow: Direct Solutions 293
8.17 Single-Pipe Flow: Automated Solutions 296
8.18 Empirical Equations for Single-Pipe Flow 298
8.19 Nonrigorous Head-Loss Equations 300
8.20 Minor Losses in Turbulent Flow 301
8.21 Loss of Head at Entrance 302
8.22 Loss of Head at Submerged Discharge 303
8.23 Loss Due to Contraction 305
8.24 Loss Due to Expansion 307
8.25 Loss in Pipe Fittings 312
8.26 Loss in Bends and Elbows 312
8.27 Single-Pipe Flow with Minor Losses 315
8.28 Pipeline with Pump or Turbine 321
8.29 Branching Pipes 326
8.30 Pipes in Series 333
8.31 Pipes in Parallel 336
8.32 Pipe Networks 339
8.33 Further Topics in Pipe Flow 343

Problems 344

Chapter 9 Forces on Immersed Bodies 356

9.1 Introduction 356
9.2 Friction Drag of Boundary Layer—Incompressible Flow 358
9.3 Laminar Boundary Layer for Incompressible Flow Along a Smooth Flat Plate 360
9.4 Turbulent Boundary Layer for Incompressible Flow Along a Smooth Flat Plate 365
9.5 Friction Drag for Incompressible Flow Along a Smooth Flat Plate with a Transition Regime 369
9.6 Boundary-Layer Separation and Pressure Drag 372
9.7 Drag on Three-Dimensional Bodies (Incompressible Flow) 374
9.8 Drag on Two-Dimensional Bodies (Incompressible Flow) 382
9.9 Lift and Circulation 385
9.10 Ideal Flow About a Cylinder 387
9.11 Lift of an Airfoil 390
9.12 Induced Drag on Airfoil of Finite Length 392
9.13 Lift and Drag Diagrams 395
9.14 Effects of Compressibility on Drag and Lift 399
9.15 Concluding Remarks 401

Problems 402

Chapter 10 Steady Flow in Open Channels 407

10.1 Open Channels 407
10.2 Uniform Flow 409
10.3 Solution of Uniform Flow Problems 414
10.4 Velocity Distribution in Open Channels 419
10.5 "Wide and Shallow" Flow 421
10.6 Most Efficient Cross Section 422
10.7 Circular Sections Not Flowing Full 426
10.8 Laminar Flow in Open Channels 429
10.9 Specific Energy and Alternate Depths of Flow in Rectangular Channels 431
10.10 Subcritical and Supercritical Flow 436
10.11 Critical Depth in Nonrectangular Channels 438
10.12 Occurrence of Critical Depth 441
10.13 Humps and Contractions 442
10.14 Nonuniform, or Varied, Flow 448
10.15 Energy Equation for Gradually Varied Flow 449
10.16 Water-Surface Profiles in Gradually Varied Flow (Rectangular Channels) 452
10.17 Examples of Water-Surface Profiles 456

10.18 The Hydraulic Jump 460
10.19 Location of Hydraulic Jump 465
10.20 Velocity of Gravity Waves 468
10.21 Flow Around Channel Bends 471
10.22 Transitions 474
10.23 Hydraulics of Culverts 476
10.24 Further Topics in Open-Channel Flow 480
Problems 481

Chapter 11 Fluid Measurements 491

11.1 Measurement of Fluid Properties 491
11.2 Measurement of Static Pressure 495
11.3 Measurement of Velocity with Pitot Tubes 496
11.4 Measurement of Velocity by Other Methods 500
11.5 Measurement of Discharge 503
11.6 Orifices, Nozzles, and Tubes 505
11.7 Venturi Meter 515
11.8 Flow Nozzle 519
11.9 Orifice Meter 522
11.10 Flow Measurement of Compressible Fluids 524
11.11 Thin-Plate Weirs 527
11.12 Streamlined Weirs and Free Overfall 533
11.13 Overflow Spillway 536
11.14 Sluice Gate 538
11.15 Measurement of Liquid-Surface Elevation 540
11.16 Other Methods of Measuring Discharge 540
Problems 541

Chapter 12 Unsteady-Flow Problems 546

12.1 Introduction 546
12.2 Discharge with Varying Head 546
12.3 Unsteady Flow of Incompressible Fluids in Pipes 550
12.4 Approach to Steady Flow 554
12.5 Velocity of Pressure Wave in Pipes 558
12.6 Water Hammer 559
12.7 Surge Tanks 569
Problems 574

Chapter 13 Steady Flow of Compressible Fluids 580

13.1 Thermodynamic Considerations 580
13.2 Fundamental Equations Applicable to the Flow of Compressible Fluids 584
13.3 Speed of Sound 585
13.4 Adiabatic Flow (With or Without Friction) 588
13.5 Stagnation Properties 589
13.6 Isentropic Flow 593
13.7 Effect of Area Variation on One-Dimensional Compressible Flow 594
13.8 Compressible Flow Through a Converging Nozzle 596
13.9 Isentropic Flow Through a Converging-Diverging Nozzle 600
13.10 One-Dimensional Shock Wave 603
13.11 The Oblique Shock Wave 607
13.12 Isothermal Flow 609
13.13 Isothermal Flow in a Constant-Area Duct 610
13.14 Adiabatic Flow in a Constant-Area Duct 614
13.15 Comparison of Flow Types 618
13.16 Concluding Remarks 619
Problems 619

Chapter 14 Ideal Flow Mathematics 622

14.1 Differential Equation of Continuity 622
14.2 Irrotational Flow 625
14.3 Circulation and Vorticity 627
14.4 The Stream Function 629
14.5 Basic Flow Fields 631
14.6 Velocity Potential 635

14.7 Orthogonality of Streamlines and Equipotential Lines 636
14.8 Flow Through Porous Media 639
Problems 642

Chapter 15 Hydraulic Machinery—Pumps 647

15.1 Description of Centrifugal and Axial-Flow Pumps 647
15.2 Head Developed by a Pump 651
15.3 Pump Efficiency 652
15.4 Similarity Laws for Pumps 652
15.5 Performance Characteristics of Pumps at Constant Speed 655
15.6 Performance Characteristics at Different Speeds and Sizes 658
15.7 Operating Point of a Pump 660
15.8 Specific Speed of Pumps 662
15.9 Peripheral-Velocity Factor 665
15.10 Cavitation in Pumps 666
15.11 Viscosity Effect 671
15.12 Selection of Pumps 671
15.13 Pumps Operating in Series and in Parallel 675
15.14 Pump Installations 677
Problems 679

Chapter 16 Hydraulic Machinery—Turbines 685

16.1 Hydraulic Turbines 685
16.2 Impulse Turbines 686
16.3 Action of the Impulse Turbine 689
16.4 Head on an Impulse Turbine and Efficiency 691
16.5 Nozzles for Impulse Turbines 695
16.6 Reaction Turbines 697
16.7 Action of the Reaction Turbine 701
16.8 Draft Tubes and Effective Head on Reaction Turbines 702
16.9 Efficiency of Turbines 706
16.10 Similarity Laws for Reaction Turbines 708
16.11 Peripheral-Velocity Factor and Specific Speed of Turbines 711
16.12 Cavitation in Turbines 713
16.13 Selection of Turbines 717
16.14 Pump Turbine 719
16.15 Turbine Installations 720
Problems 722

Appendixes

A ***Fluid and Geometric Properties 729***
B ***Equations in Fluid Mechanics 740***
C ***Programming and Computer Applications 745***
D ***Examples of Using Solvers 754***
E ***References 764***
F ***Answers to Exercises 769***

Index 777