Table of Contents

- 1 Introduction p. 1
- 1.1 Some Characteristics of Fluids p. 2
- 1.2 Dimensions, Dimensional Homogeneity, and Units p. 2
- 1.2.1 Systems of Units p. 5
- 1.3 Analysis of Fluid Behavior p. 7
- 1.4 Measures of Fluid Mass and Weight p. 8
- 1.4.1 Density p. 8
- 1.4.2 Specific Weight p. 8
- 1.4.3 Specific Gravity p. 9
- 1.5 Ideal Gas Law p. 9
- 1.6 Viscosity p. 11
- 1.7 Compressibility of Fluids p. 15
- 1.7.1 Bulk Modulus p. 15
- 1.7.2 Compression and Expansion of Gases p. 16
- 1.7.3 Speed of Sound p. 17
- 1.8 Vapor Pressure p. 18
- 1.9 Surface Tension p. 18
- 1.10 Chapter Summary and Study Guide Problems p. 21
- 2 Fluid Statics p. 28
- 2.1 Pressure at a Point p. 29
- 2.2 Basic Equation for Pressure Field p. 30
- 2.3 Pressure Variation in a Fluid at Rest p. 31
- 2.3.1 Incompressible Fluid p. 32
- 2.3.2 Compressible Fluid p. 34
- 2.4 Standard Atmosphere p. 35
- 2.5 Measurement of Pressure p. 35
- 2.6 Manometry p. 37
- 2.6.1 Piezometer Tube p. 37
- 2.6.2 U-Tube Manometer p. 38
- 2.6.3 Inclined-Tube Manometer p. 41
- 2.7 Mechanical and Electronic Pressure Measuring Devices p. 42
- 2.8 Hydrostatic Force on a Plane Surface p. 43
- 2.9 Pressure Prism p. 47
- 2.10 Hydrostatic Force on a Curved Surface p. 49
- 2.11 Buoyancy, Flotation, and Stability p. 52
- 2.11.1 Archimedes' Principle p. 52
- 2.11.2 Stability p. 53
- 2.12 Pressure Variation in a Fluid with Rigid-Body Motion p. 55
- 2.13 Chapter Summary and Study Guide p. 55
- References p. 56
- 3.2 F = ma Along a Streamline p. 68
- Problems p. 56
- 3 Elementary Fluid Dynamics-The Bernoulli Equation p. 66
- 3.1 Newton's Second Law p. 67

- 3.3 F = ma Normal to a Streamline p. 71
- 3.4 Physical Interpretation p. 73
- 3.5 Static, Stagnation, Dynamic, and Total Pressure p. 75
- 3.6 Examples of Use of the Bernoulli Equation p. 78
- 3.6.1 Free Jets p. 78
- 3.6.2 Confined Flows p. 79
- 3.6.3 Flowrate Measurement p. 85
- 3.7 The Energy Line and the Hydraulic Grade Line p. 88
- 3.8 Restrictions on the Use of the Bernoulli Equation p. 90
- 3.9 Chapter Summary and Study Guide p. 91
- Problems p. 92
- 4 Fluid Kinematics p. 101
- 4.1 The Velocity Field p. 101
- 4.1.1 Eulerian and Lagrangian Flow Descriptions p. 103
- 4.1.2 One-, Two-, and Three- Dimensional Flows p. 104
- 4.1.3 Steady and Unsteady Flows p. 104
- 4.1.4 Streamlines, Streaklines, and Pathlines p. 105
- 4.2 The Acceleration Field p. 108
- 4.2.1 The Material Derivative p. 108
- 4.2.2 Unsteady Effects p. 111
- 4.2.3 Convective Effects p. 111
- 4.4.1 Derivation of the Reynolds Transport Theorem p. 114
- 4.2.4 Streamline Coordinates p. 112
- 4.3 Control Volume and System Representations p. 113
- 4.4 The Reynolds Transport Theorem p. 114
- 4.4.2 Selection of a Control Volume p. 117
- 4.5 Chapter Summary and Study Guide p. 118
- References p. 118
- Problems p. 119
- 5 Finite Control Volume Analysis p. 123
- 5.1 Conservation of Mass-The Continuity Equation p. 123
- 5.1.1 Derivation of the Continuity Equation p. 123
- 5.1.2 Fixed, Nondeforming Control Volume p. 125
- 5.1.3 Moving, Nondeforming Control Volume p. 129
- 5.2 Newton's Second Law-The Linear Momentum and Moment-of-Momentum Equations p. 130
- 5.2.1 Derivation of the Linear Momentum Equation p. 130
- 5.2.2 Application of the Linear Momentum Equation p. 132
- 5.2.3 Derivation of the Moment-of-Momentum Equation p. 142
- 5.2.4 Application of the Moment-of-Momentum Equation p. 143
- 5.3 First Law of Thermodynamics-The Energy Equation p. 150
- 5.3.1 Derivation of the Energy Equation p. 150
- 5.3.2 Application of the Energy Equation p. 153
- 5.3.3 Comparison of the Energy Equation with the Bernoulli Equation p. 155
- 5.3.4 Application of the Energy Equation to Nonuniform Flows p. 160
- 5.4 Chapter Summary and Study Guide p. 162

- Problems p. 163
- 6 Differential Analysis of Fluid Flow p. 177
- 6.1 Fluid Element Kinematics p. 178
- 6.1.1 Velocity and Acceleration Fields Revisited p. 178
- 6.1.2 Linear Motion and Deformation p. 179
- 6.1.3 Angular Motion and Deformation p. 180
- 6.2 Conservation of Mass p. 184
- 6.2.1 Differential Form of Continuity Equation p. 184
- 6.2.2 Cylindrical Polar Coordinates p. 186
- 6.2.3 The Stream Function p. 187
- 6.3 Conservation of Linear Momentum p. 190
- 6.3.1 Description of Forces Acting on Differential Element p. 191
- 6.3.2 Equations of Motion p. 193
- 6.4 Inviscid Flow p. 194
- 6.4.1 Euler's Equations of Motion p. 194
- 6.4.2 The Bernoulli Equation p. 195
- 6.4.3 Irrotational Flow p. 197
- 6.4.4 The Bernoulli Equation for Irrotational Flow p. 197
- 6.4.5 The Velocity Potential p. 198
- 6.5 Some Basic, Plane Potential Flows p. 201
- 6.5.1 Uniform Flow p. 203
- 6.5.2 Source and Sink p. 203
- 6.5.3 Vortex p. 205
- 6.5.4 Doublet p. 209
- 6.6 Superposition of Basic, Plane Potential Flows p. 211
- 6.8 Viscous Flow p. 221
- 6.6.1 Source in a Uniform Stream-Half-Body p. 211
- 6.6.2 Flow around a Circular Cylinder p. 214
- 6.7 Other Aspects of Potential Flow Analysis p. 220
- 6.8.1 Stress-Deformation Relationships p. 221
- 6.8.2 The Navier-Stokes Equations p. 222
- 6.9 Some Simple Solutions for Viscous, Incompressible Fluids p. 223
- 6.9.1 Steady, Laminar Flow between Fixed Parallel Plates p. 223
- 6.9.2 Couette Flow p. 226
- 6.9.3 Steady, Laminar Flow in Circular Tubes p. 228
- 6.10 Other Aspects of Differential Analysis p. 230
- 6.11 Chapter Summary and Study Guide p. 231
- References p. 232
- Problems p. 233
- 7 Similitude, Dimensional Analysis, and Modeling p. 240
- 7.1 Dimensional Analysis p. 241
- 7.2 Buckingham Pi Theorem p. 242
- 7.3 Determination of Pi Terms p. 243
- 7.4 Some Additional Comments about Dimensional Analysis p. 248
- 7.4.1 Selection of Variables p. 248
- 7.4.2 Determination of Reference Dimensions p. 249

- 7.4.3 Uniqueness of Pi Terms p. 249
- 7.5 Determination of Pi Terms by Inspection p. 250
- 7.6 Common Dimensionless Groups in Fluid Mechanics p. 251
- 7.7 Correlation of Experimental Data p. 252
- 7.7.1 Problems with One Pi Term p. 252
- 7.7.2 Problems with Two or More Pi Terms p. 253
- 7.8 Modeling and Similitude p. 255
- 7.8.1 Theory of Models p. 256
- 7.8.2 Model Scales p. 259
- 7.8.3 Distorted Models p. 260
- 7.9 Some Typical Model Studies p. 262
- 7.9.1 Flow through Closed Conduits p. 262
- 7.9.2 Flow around Immersed Bodies p. 264
- 7.9.3 Flow with a Free Surface p. 266
- 7.10 Chapter Summary and Study Guide p. 269
- References p. 270
- Problems p. 270
- 8.1.2 Entrance Region and Fully Developed Flow p. 281
- 8 Viscous Flow in Pipes p. 278
- 8.1 General Characteristics of Pipe Flow p. 279
- 8.1.1 Laminar or Turbulent Flow p. 279
- 8.2 Fully Developed Laminar Flow p. 282
- 8.2.1 From F = ma Applied to a Fluid Element p. 282
- 8.2.2 From the Navier-Stokes Equations p. 286
- 8.3 Fully Developed Turbulent Flow p. 286
- 8.3.1 Transition from Laminar to Turbulent Flow p. 287
- 8.3.2 Turbulent Shear Stress p. 288
- 8.3.3 Turbulent Velocity Profile p. 289
- 8.4 Dimensional Analysis of Pipe Flow p. 289
- 8.4.1 Major Losses p. 290
- 8.4.2 Minor Losses p. 294
- 8.4.3 Noncircular Conduits p. 301
- 8.5 Pipe Flow Examples p. 303
- 8.5.1 Single Pipes p. 303
- 8.5.2 Multiple Pipe Systems p. 310
- 8.6 Pipe Flowrate Measurement p. 311
- 8.7 Chapter Summary and Study Guide p. 315
- References p. 317
- Problems p. 317
- 9 Flow Over Immersed Bodies p. 326
- 9.1 General External Flow Characteristics p. 327
- 9.1.1 Lift and Drag Concepts p. 328
- 9.1.2 Characteristics of Flow Past an Object p. 330
- 9.2 Boundary Layer Characteristics p. 333
- 9.2.1 Boundary Layer Structure and Thickness on a Flat Plate p. 333
- 9.2.2 Prandt1/Blasius Boundary Layer Solution p. 335

- 9.2.4 Transition from Laminar to Turbulent Flow p. 340
- 9.2.5 Turbulent Boundary Layer Flow p. 341
- 9.2.6 Effects of Pressure Gradient p. 343
- 9.3 Drag p. 346
- 9.3.1 Friction Drag p. 347
- 9.3.2 Pressure Drag p. 347
- 9.3.3 Drag Coefficient Data and Examples p. 348
- 9.4 Lift p. 361
- 9.4.1 Surface Pressure Distribution p. 361
- 9.4.2 Circulation p. 365
- 9.5 Chapter Summary and Study Guide p. 367
- References p. 367
- Problems p. 368
- 10 Open-Channel Flow p. 376
- 10.1 General Characteristics of Open-Channel Flow p. 376
- 10.2 Surface Waves p. 377
- 10.2.1 Wave Speed p. 377
- 10.2.2 Froude Number Effects p. 379
- 10.3 Energy Considerations p. 380
- 10.3.1 Specific Energy p. 381
- 10.4 Uniform Depth Channel Flow p. 384
- 10.4.1 Uniform Flow Approximations p. 384
- 10.4.2 The Chezy and Manning Equations p. 384
- 10.6.2 Sharp-Crested Weirs p. 397
- 9.2.3 Momentum Integral Boundary Layer Equation for a Flat Plate p. 337
- 10.4.3 Uniform Depth Examples p. 387
- 10.5 Gradually Varied Flow p. 392
- 10.6 Rapidly Varied Flow p. 392
- 10.6.1 The Hydraulic Jump p. 393
- 10.6.3 Broad-Crested Weirs p. 399
- 10.6.4 Underflow Gates p. 402
- 10.7 Chapter Summary and Study Guide p. 403
- References p. 404
- Problems p. 405
- 11 Turbomachines p. 410
- 11.1 Introduction p. 410
- 11.2 Basic Energy Considerations p. 411
- 11.3 Basic Angular Momentum Considerations p. 415
- 11.4 The Centrifugal Pump p. 417
- 11.4.1 Theoretical Considerations p. 417
- 11.4.2 Pump Performance Characteristics p. 421
- 11.4.3 System Characteristics and Pump Selection p. 423
- 11.5 Dimensionless Parameters and Similarity Laws p. 426
- 11.5.1 Specific Speed p. 429
- 11.6 Axial-Flow and Mixed-Flow Pumps p. 430
- 11.7 Turbines p. 433

- 11.7.1 Impulse Turbines p. 434
- 11.7.2 Reaction Turbines p. 440
- 11.8 Compressible Flow Turbomachines p. 443
- 11.9 Chapter Summary and Study Guide p. 444
- References p. 445
- Problems p. 446
- A Computational Fluid Dynamics and Flowlab p. 454
- B Physical Properties of Fluids p. 469
- C Properties of the U.S. Standard Atmosphere p. 475
- D Reynolds Transport Theorem p. 477
- G Review Problems
- D.1 General Reynolds Transport Theorem p. 477
- D.2 General Control Volume Equations p. 479
- E Comprehensive Table of Conversion Factors p. 483
- Online Appendix List p. 487
- F Video Library
- H Laboratory Problems
- I CFD Driven Cavity Example
- J Flowlab Tutorial and User's Guide
- K Flowlab Problems
- Answers p. 488
- Index p. 493
- Index of Fluids Phenomena Videos p. 504