CONTENTS

List of Symbols /XI
To the Student /XIX

PART 1 FLOWS OF INCOMPRESSIBLE FLUIDS – 1 1

CHAPTER 1 KINEMATICS OF THE FLOW FIELD 3
1.1 Introduction /3
1.2 Mass Conservation, Stream Function, and Streamline /9
1.3 Rotation and Deformation /21

CHAPTER 2 DYNAMICS OF THE FLOW FIELD 33
2.1 Forces and Stresses /33
2.2 Equations of Motion /39
2.3 Newtonian Fluids and the Navier-Stokes Equations /42
2.4 Non-Newtonian Fluids /50

CHAPTER 3 SIMPLE EXACT SOLUTIONS 55
3.1 Flows between Parallel Plates /54
3.2 Steady Channel Flows /61

3.3 Steady Film Flows over a Flat Plate /63
3.4 Steady Channel Flows with Blowing and Suction /66

CHAPTER 4 MORE EXACT SOLUTIONS 68
4.1 Rayleigh Problem /68
4.2 Steady Stagnation-Point Flow /76

CHAPTER 5 SOME APPROXIMATE SOLUTIONS 84
5.1 Nondimensionalization and Governing Dimensionless Parameters /84
5.2 The Ordering Process and the Use of Asymptotics as an Approximation /87
5.3 Transient Channel Flows /92
5.4 Flow Induced by an Oscillating Plate /101
5.5 Lubrication of a Slipper Bearing /105

CHAPTER 6 OUTER REGION OF A HIGH-*Re* FLOW FIELD 112
6.1 Introduction /112
6.2 High-*Re* Flow Past a Flat Wall /120
6.3 The Outer Flow /129

CHAPTER 7 THE BOUNDARY LAYER OF A HIGH-*Re* FLOW FIELD 139
7.1 The Falkner-Skan Flows /139
7.2 Blasius Flow /145
7.3 Falkner-Skan Flows and Separation of the Boundary Layer /151
7.4 Kármán-Pohlhausen Technique /153
7.5 Jets and Wakes /159

PART 2 FLOWS OF INCOMPRESSIBLE FLUIDS—2 175

CHAPTER 8 PLANE FLOWS IN POLAR COORDINATES 177
8.1 Introduction /177
8.2 Couette Flow /185
8.3 Jeffery-Hamel Flow /190
8.4 Jeffery-Hamel Flow (continued) /199
8.5 Boundary-Layer Flow in a Convergent Channel /208
8.6 Small-*Re* Flow Past a Circular Cylinder /216

CHAPTER 9 NONPLANE AND AXISYMMETRIC FLOWS 226
9.1 Introduction /226
9.2 Pseudo-plane, Axisymmetric, and Pseudo-axisymmetric Flows /281

9.3 Poiseuille Flow /228
9.4 The Rotating Disk /242
9.5 Boundary Layer on a Yawed Flat Wall /247
9.6 Axisymmetric Jet /249
9.7 Small-Re Flow Past a Sphere /253

CHAPTER 10 INTRODUCTION TO TURBULENT FLOWS 257
10.1 Random Nature of Turbulence /257
10.2 Reynolds Equations and Reynolds Stresses /260
10.3 Turbulent Flow Between Fixed Parallel Plates /263
10.4 Turbulent Boundary-Layer Flow Past a Flat Plate /272

PART 3 FLOWS OF COMPRESSIBLE FLUIDS 277

CHAPTER 11 FROM VECTORS TO DYADICS 279
11.1 Introduction /279
11.2 The Operator ∇ /283
11.3 Dyadics and Dyadic Operations /289
11.4 General Properties of ∇ /297
11.5 Integral Relations /303
11.6 Vector and Dyadic Relations in General Orthogonal Coordinate Systems /309

CHAPTER 12 KINEMATICS OF FLUID FLOW 321
12.1 Introduction /321
12.2 Preliminary Considerations /326
12.3 Differentiation following the Motion /332
12.4 Rotation and Deformation /335
12.5 Kinematics of a Moving Volume Integral /342
12.6 Conservation of Mass /345
12.7 Stream Functions /349

CHAPTER 13 DYNAMICS AND ENERGETICS 353
13.1 Equation of Motion /353
13.2 First Law of Thermodynamics /358
13.3 Second Law of Thermodynamics /360
13.4 Constitutive Equations /366
13.5 Navier-Stokes Equation /372
13.6 Non-Newtonian Fluids /374
13.7 Surfaces of Discontinuity /378
13.8 The Flat Couette Flow of Compressible Fluids—A Simple Example /381
13.9 Rayleigh Problem at Large Times for Compressible Fluids—A Boundary-Layer Flow /388

A READING LIST FOR FURTHER STUDIES 396
A LIST OF PRE-1900 WORKS CITED 399
APPENDIX GOVERNING EQUATIONS 401
PROBLEMS 406
INDEX 431