

CONTENTS

xiii

Preface

Part I Governing Equations

1 Basic Conservation Laws 3

1-1 Statistical and Continuum Methods 4

1-2 Eulerian and Lagrangian Coordinates 6

1-3 Material Derivative 7

1-4 Control Volumes 8

1-5 Reynolds' Transport Theorem 9

1-6 Conservation of Mass 12

1-7 Conservation of Momentum 14

1-8 Conservation of Energy 17

1-9 Discussion of Conservation Equations 21

1-10 Rotation and Rate of Shear 22

1-11 Constitutive Equations 25

1-12 Viscosity Coefficients 29

1-13 Navier-Stokes Equations 31

1-14	Energy Equation	32
1-15	Governing Equations for Newtonian Fluids	33
1-16	Boundary Conditions	35
	Problems	36
2	Flow Kinematics	37
2-1	Flow Lines	37
2-2	Circulation and Vorticity	43
2-3	Stream Tubes and Vortex Tubes	44
2-4	Kinematics of Vortex Lines	46
	Problems	48
3	Special Forms of the Governing Equations	49
3-1	Kelvin's Theorem	50
3-2	Bernoulli Equation	53
3-3	Crocco's Equation	55
3-4	Vorticity Equation	58
	Problems	60
	Further Reading	60
Part II	Ideal-Fluid Flow	
	Governing Equations and Boundary Conditions	62
	Potential Flows	63
4	Two-dimensional Potential Flows	65
4-1	Stream Function	66
4-2	Complex Potential and Complex Velocity	69
4-3	Uniform Flows	71
4-4	Source, Sink, and Vortex Flows	73
4-5	Flow in a Sector	76
4-6	Flow around a Sharp Edge	78
4-7	Flow due to a Doublet	79
4-8	Circular Cylinder without Circulation	82
4-9	Circular Cylinder with Circulation	84
4-10	Blasius' Integral Laws	89
4-11	Force and Moment on a Circular Cylinder	93
4-12	Conformal Transformations	95
4-13	Joukowski Transformation	100
4-14	Flow around Ellipses	102
4-15	Kutta Condition and the Flat-Plate Airfoil	106

4-16 Symmetrical Joukowski Airfoil	109
4-17 Circular-Arc Airfoil	114
4-18 Joukowski Airfoil	118
4-19 Schwarz-Christoffel Transformation	120
4-20 Source in a Channel	122
4-21 Flow through an Aperture	125
4-22 Flow past a Vertical Flat Plate	132
Problems	140
5 Three-dimensional Potential Flows	143
5-1 Velocity Potential	144
5-2 Stokes' Stream Function	145
5-3 Solution of the Potential Equation	147
5-4 Uniform Flow	149
5-5 Source and Sink	151
5-6 Flow due to a Doublet	153
5-7 Flow near a Blunt Nose	155
5-8 Flow around a Sphere	157
5-9 Line-distributed Source	157
5-10 Sphere in the Flow Field of a Source	160
5-11 Rankine Solids	162
5-12 d'Alembert's Paradox	164
5-13 Forces Induced by Singularities	167
5-14 Kinetic Energy of a Moving Fluid	172
5-15 Apparent Mass	174
Problems	175
6 Surface Waves	178
6-1 The General Surface-Wave Problem	179
6-2 Small-Amplitude Plane Waves	181
6-3 Propagation of Surface Waves	183
6-4 Effect of Surface Tension	186
6-5 Shallow-Liquid Waves of Arbitrary Form	189
6-6 Complex Potential for Traveling Waves	193
6-7 Particle Paths for Traveling Waves	195
6-8 Standing Waves	198
6-9 Particle Paths for Standing Waves	199
6-10 Waves in Rectangular Vessels	201
6-11 Waves in Cylindrical Vessels	205

6-12	Propagation of Waves at an Interface	209
	Problems	214
	Further Reading	218
Part III Viscous Flows of Incompressible Fluids		
7	Exact solutions	223
7-1	Couette Flow	224
7-2	Poiseuille Flow	226
7-3	Flow between Rotating Cylinders	229
7-4	Stokes' First Problem	231
7-5	Stokes' Second Problem	235
7-6	Pulsating Flow between Parallel Surfaces	237
7-7	Stagnation-Point Flow	239
7-8	Flow in Convergent and Divergent Channels	244
7-9	Flow over a Porous Wall	247
	Problems	250
8	Low-Reynolds-Number Solutions	252
8-1	The Stokes Approximation	253
8-2	Uniform Flow	255
8-3	Doublet	255
8-4	Rotlet	257
8-5	Stokeslet	262
8-6	Rotating Sphere in a Fluid	267
8-7	Uniform Flow past a Sphere	268
8-8	Uniform Flow past a Circular Cylinder	270
8-9	The Oseen Approximation	273
	Problems	274
9	Boundary Layers	276
9-1	Boundary-Layer Thicknesses	278
9-2	The Boundary-Layer Equations	279
9-3	Blasius' Solution	283
9-4	Falkner-Skan Solutions	287
9-5	Flow over a Wedge	291
9-6	Stagnation-Point Flow	293
9-7	Flow in a Convergent Channel	294
9-8	Approximate Solution for a Flat Surface	295
9-9	General Momentum Integral	300
9-10	Kármán-Pohlhausen Approximation	302

9-11 Boundary-Layer Separation	310
9-12 Stability of Boundary Layers	313
Problems	318
Further Reading	320
Part IV Compressible Flow of Inviscid Fluids	
Governing Equations and Boundary Conditions	322
10 Shock Waves	327
10-1 Propagation of Infinitesimal Disturbances	328
10-2 Propagation of Finite Disturbances	332
10-3 Rankine-Hugoniot Equations	337
10-4 Conditions for Normal Shock Waves	340
10-5 Normal-Shock-Wave Equations	344
10-6 Oblique Shock Waves	346
Problems	354
11 One-dimensional Flows	356
11-1 Weak Waves	357
11-2 Weak Shock Tubes	360
11-3 Wall Reflection of Waves	363
11-4 Reflection and Refraction at an Interface	366
11-5 Piston Problem	369
11-6 Finite-Strength Shock Tubes	371
11-7 Nonadiabatic Flows	376
11-8 Isentropic-Flow Relations	380
11-9 Flow through Nozzles	381
Problems	383
12 Multi-dimensional Flows	386
12-1 Irrotational Motion	387
12-2 Janzen-Rayleigh Expansion	389
12-3 Small-Perturbation Theory	391
12-4 Pressure Coefficient	393
12-5 Flow over a Wave-shaped Wall	394
12-6 Prandtl-Glauert Rule for Subsonic Flow	400
12-7 Ackeret's Theory for Supersonic Flows	402
12-8 Prandtl-Meyer Flow	407
Problems	410
Further Reading	412

Appendixes	413
A Vector Analysis	413
B Tensors	417
C Governing Equations	421
D Complex Variables	424
E Thermodynamics	430
Index	435
10 Shock Waves	435
10-1 Propagation of Irrotational Disturbances	435
10-2 Propagation of Finite Disturbances	435
10-3 Rankine-Hugoniot Relations	435
10-4 Conditions for Normal Shock Waves	435
10-5 Normal Shock Wave Relations	435
10-6 Oblique Shock Waves	435
10-7 Problems	435
11 One-dimensional Transonic and Supersonic Flow	435
11-1 Wave Waves	435
11-2 Wave Shock Tubes	435
11-3 Wall Reflection of Waves	435
11-4 Reflection and Refraction at an Interface	435
11-5 Piston Problem	435
11-6 Finite-Strain Shock Tubes and a Related Problem	435
11-7 Nonadiabatic Flow	435
11-8 Isentropic Flow Relations	435
11-9 Flow through Nozzles	435
11-10 Problems	435
12 Multi-dimensional Flow	435
12-1 Irrotational Motion	435
12-2 Laminar-Rayleigh Expansion	435
12-3 Small-Deflection Theory	435
12-4 Pressure Coefficient	435
12-5 Flow over a Wavy-shaped Wall	435
12-6 Prandtl-Glauert Rule for Subsonic Flow	435
12-7 Asymptotic Theory for Supersonic Flow	435
12-8 Prandtl-Meyer Flow	435
12-9 Problems	435
Further Reading	435