

Contents

1	The Concept of the Continuum and Kinematics	1
1.1	Properties of Fluids, Continuum Hypothesis	1
1.2	Kinematics	7
1.2.1	Material and Spatial Descriptions	7
1.2.2	Pathlines, Streamlines, Streaklines	10
1.2.3	Differentiation with Respect to Time	14
1.2.4	State of Motion, Rate of Change of Line, Surface and Volume Elements	17
1.2.5	Rate of Change of Material Integrals	29
2	Fundamental Laws of Continuum Mechanics	35
2.1	Conservation of Mass, Equation of Continuity	35
2.2	Balance of Momentum	37
2.3	Balance of Angular Momentum	44
2.4	Momentum and Angular Momentum in an Accelerating Frame	46
2.5	Applications to Turbomachines	54
2.6	Balance of Energy	65
2.7	Balance of Entropy	69
2.8	Thermodynamic Equations of State	71
3	Constitutive Relations for Fluids	75
4	Equations of Motion for Particular Fluids	95
4.1	Newtonian Fluids	95
4.1.1	The Navier-Stokes Equations	95
4.1.2	Vorticity Equation	98
4.1.3	Effect of Reynolds' Number	100
4.2	Inviscid Fluids	106
4.2.1	Euler's Equations	106
4.2.2	Bernoulli's Equation	107
4.2.3	Vortex Theorems	112
4.2.4	Integration of the Energy Equation	138
4.3	Initial and Boundary Conditions	141
4.4	Simplification of the Equations of Motion	145

5	Hydrostatics	151
5.1	Hydrostatic Pressure Distribution	151
5.2	Hydrostatic Lift, Force on Walls	156
5.3	Free Surfaces	162
6	Laminar Unidirectional Flows	167
6.1	Steady Unidirectional Flow	168
6.1.1	Couette Flow	168
6.1.2	Couette-Poiseuille Flow	169
6.1.3	Flow Down an Inclined Plane	171
6.1.4	Flow Between Rotating Concentric Cylinders	174
6.1.5	Hagen-Poiseuille Flow	175
6.1.6	Flow Through Noncircular Conduits	180
6.2	Unsteady Unidirectional Flows	183
6.2.1	Flow Due to a Wall Which Oscillates in its Own Plane	183
6.2.2	Flow Due to a Wall Which is Suddenly Set in Motion	186
6.3	Unidirectional Flows of Non-Newtonian Fluids	188
6.3.1	Steady Flow Through a Circular Pipe	188
6.3.2	Steady Flow Between a Rotating Disk and a Fixed Wall	190
6.3.3	Unsteady Unidirectional Flows of a Second Order Fluid	191
6.4	Unidirectional Flows of a Bingham Material	197
6.4.1	Channel Flow of a Bingham Material	197
6.4.2	Pipe Flow of a Bingham Material	202
7	Fundamentals of Turbulent Flow	205
7.1	Stability and the Onset of Turbulence	205
7.2	Reynolds' Equations	207
7.3	Turbulent Shear Flow Near a Wall	213
7.4	Turbulent Flow in Smooth Pipes and Channels	223
7.5	Turbulent Flow in Rough Pipes	226
8	Hydrodynamic Lubrication	229
8.1	Reynolds' Equation of Lubrication Theory	229
8.2	Statically Loaded Bearing	232
8.2.1	Infinitely Long Journal Bearing	232
8.2.2	Infinitely Short Journal Bearing	238
8.2.3	Journal Bearing of Finite Length	239
8.3	Dynamically Loaded Bearings	240
8.3.1	Infinitely Long Journal Bearing	240
8.3.2	Dynamically Loaded Slider Bearing	241
8.3.3	Squeeze Flow of a Bingham Material	246
8.4	Thin-Film Flow on a Semi-Infinite Wall	249

8.5	Flow Through Particle Filters	252
8.6	Flow Through a Porous Medium	254
8.7	Hele-Shaw Flows	258
9	Stream Filament Theory	261
9.1	Incompressible Flow	261
9.1.1	Continuity Equation	262
9.1.2	Inviscid Flow	263
9.1.3	Viscous Flow	266
9.1.4	Application to Flows with Variable Cross-Section ...	271
9.1.5	Viscous Jet	276
9.2	Steady Compressible Flow	279
9.2.1	Flow Through Pipes and Ducts with Varying Cross-Section	279
9.2.2	Constant Area Flow	290
9.2.3	The Normal Shock Wave Relations	294
9.3	Unsteady Compressible Flow	299
10	Potential Flows	315
10.1	One-Dimensional Propagation of Sound	316
10.2	Steady Compressible Potential Flow	323
10.3	Incompressible Potential Flow	324
10.3.1	Simple Examples of Potential Flows	326
10.3.2	Virtual Masses	348
10.4	Plane Potential Flow	354
10.4.1	Examples of Incompressible, Plane Potential Flows ...	354
10.4.2	Complex Potential for Plane Flows	358
10.4.3	Blasius' Theorem	367
10.4.4	Kutta-Joukowski Theorem	370
10.4.5	Conformal Mapping	372
10.4.6	Schwarz-Christoffel Transformation	374
10.4.7	Free Jets	376
10.4.8	Flow Around Airfoils	382
10.4.9	Approximate Solution for Slender Airfoils in Incompressible Flow	388
10.4.10	Slender Airfoils in Compressible Flow	395
11	Supersonic Flow	399
11.1	Oblique Shock Wave	400
11.2	Detached Shock Wave	402
11.3	Reflection of Oblique Shock Waves	403
11.4	Supersonic Potential Flow Past Slender Airfoils	405
11.5	Prandtl-Meyer Flow	408
11.6	Shock Expansion Theory	414

12	Boundary Layer Theory	417
12.1	Solutions of the Boundary Layer Equations	421
12.1.1	Flat Plate	422
12.1.2	Wedge Flows	426
12.1.3	Unsteady Stagnation Point Flow	428
12.1.4	Flow Past a Body	429
12.2	Temperature Boundary Layer in Forced Convection	431
12.3	Temperature Boundary Layer in Natural Convection	437
12.4	Integral Methods of Boundary Layer Theory	440
12.5	Turbulent Boundary Layers	443
13	Creeping Flows	451
13.1	Plane and Axially-Symmetric Flows	451
13.1.1	Examples of Plane Flows	453
13.1.2	Plane Creeping Flow Round a Body (Stokes's Paradox)	465
13.1.3	Creeping Flow Round a Sphere	465
A	Introduction to Cartesian Tensors	471
A.1	Summation Convention	471
A.2	Cartesian Tensors	472
B	Curvilinear Coordinates	481
B.1	Cartesian Coordinates	488
B.2	Cylindrical Coordinates	490
B.3	Spherical Coordinates	493
C	Tables and Diagrams for Compressible Flow	497
D	Physical Properties of Air and Water	515
	References	519
	Index	521