

Contents

PREFACE		xiii
PROLOGUE		xv
CHAPTER 1 FUNDAMENTAL CONCEPTS RELATING TO FLUIDS		1
1.1 The Characteristics of Fluids		1
1.1.1 Molecular Structure		2
1.1.2 The Continuum		3
1.1.3 The Development of 'Mechanics of Fluids'		3
1.2 Properties of Fluids		4
1.2.1 Pressure		6
1.2.2 Vapour Pressure		8
1.3 The Perfect Gas: Equation of State		10
1.3.1 Changes of State		11
1.4 Compressibility		11
1.5 Viscosity		13
1.5.1 Quantitative Definition of Viscosity		13
1.5.2 The Causes of Viscosity		16
1.5.3 The Dimensional Formula and Units of Viscosity		18
1.5.4 Kinematic Viscosity and its Units		19
1.5.5 Fluidity		22
1.5.6 Non-Newtonian Liquids		22
1.5.7 Ideal Fluid		23
1.6 Surface Tension		23
1.6.1 Cohesion and Adhesion		25
Reference		27
Further Reading		27
Problems		27
CHAPTER 2 FLUIDS IN EQUILIBRIUM (FLUID 'STATICS')		29
2.1 Introduction		29
2.2 Variation of Pressure with Position in a Fluid		29
2.2.1 The Equilibrium of a Fluid of Constant Density		31
2.2.2 The Equilibrium of a Compressible Fluid		32
2.3 The Measurement of Pressure		35
2.3.1 The Barometer		35
2.3.2 Manometers		36
2.3.3 The Bourdon Gauge		41
2.3.4 Other Types of Pressure Gauge		42
2.4 Hydrostatic Thrusts on Submerged Surfaces		42
2.4.1 Thrust on a Plane Surface		42
2.4.2 Hydrostatic Thrusts on Curved Surfaces		45
2.5 Buoyancy		49
2.6 The Stability of Unconstrained Bodies in Fluids		50
2.6.1 The Stability of Submerged Bodies		50
2.6.2 The Stability of Floating Bodies		51
2.6.3 Stability of a Fluid Itself		56

2.7	Equilibrium of Moving Fluids	57
	Further Reading	60
	Problems	60
CHAPTER 3	THE PRINCIPLES OF FLUID MOTION	63
3.1	Introduction	63
3.2	Variation of Flow Parameters in Time and Space	63
3.3	Describing the Pattern of Flow	64
3.3.1	One-, Two- and Three-Dimensional Flow	65
3.3.2	Acceleration of a Fluid Particle	67
3.4	Continuity	67
3.5	Bernoulli's Equation	69
3.5.1	The Significance of the Terms in Bernoulli's Equation	72
3.6	General Equation for Steady Flow of any Fluid	74
3.6.1	The First Law of Thermodynamics	74
3.6.2	Derivation of the Steady-Flow Energy Equation	74
3.6.3	The Kinetic Energy Correction Factor	77
3.6.4	The Steady-Flow Energy Equation in Practice	79
3.6.5	Energy Transformations in a Constant-Density Fluid	80
3.7	Pressure Variation Perpendicular to Streamlines	82
3.8	Simple Applications of Bernoulli's Equation	84
3.8.1	Flow from a Sharp-Edged Orifice	84
3.8.2	The Pitot Tube	89
3.8.3	The Venturi-Meter	91
3.8.4	The Flow Nozzle and Orifice Meter	94
3.8.5	Notches and Sharp-Crested Weirs	96
	References	101
	Further Reading	101
	Problems	101
CHAPTER 4	THE MOMENTUM EQUATION	103
4.1	Introduction	103
4.2	The Momentum Equation for Steady Flow	103
4.2.1	Momentum Correction Factor for One-Dimensional Analysis	106
4.3	Applications of the Momentum Equation	107
4.3.1	The Force Caused by a Jet Striking a Surface	107
4.3.2	Force Caused by Flow Round a Pipe-Bend	109
4.3.3	Force at a Nozzle and Reaction of a Jet	112
4.3.4	Force on a Solid Body in a Flowing Fluid	115
4.3.5	Momentum Theory of a Propeller	117
	Further Reading	121
	Problems	121
CHAPTER 5	TWO KINDS OF FLOW	123
5.1	Introduction	123
5.2	Reynolds' Demonstration of the Different Kinds of Flow	123
5.3	The Criterion of Flow	126
5.3.1	The Significance of Reynolds Number	129
5.4	Laminar and Turbulent Flow in Pipes	130
5.4.1	Flows Neither Wholly Laminar nor Wholly Turbulent	133

5.4.2	The More General Occurrence of Turbulence	135
5.5	Eddy Viscosity and the Mixing Length Hypothesis	135
5.6	The Boundary Layer and the Laminar Sub-Layer	137
5.7	Distribution of Shear Stress in a Circular Pipe	139
	Further Reading	141
	Problems	141
CHAPTER 6	LAMINAR FLOW	142
6.1	Introduction	142
6.2	Steady Laminar Flow in Circular Pipes. The Hagen-Poiseuille Law	142
6.2.1	Laminar Flow of a Non-Newtonian Liquid in a Circular Pipe	146
6.3	Steady Laminar Flow between Parallel Planes	148
6.4	Steady Laminar Flow between Parallel Planes, one of which is moving	152
6.4.1	The Simple Cylindrical Dash-pot	153
6.5	Stokes' Law	155
6.6	The Measurement of Viscosity	157
6.6.1	Transpiration Methods	157
6.6.2	Industrial Viscometers	158
6.6.3	The Falling Sphere Method	159
6.6.4	Rotary Viscometers	160
6.7	Fundamentals of the Theory of Hydrodynamic Lubrication	163
6.7.1	The Inclined Slipper Bearing	165
6.7.2	The Rayleigh Step	171
6.7.3	Journal Bearings	173
6.8	Laminar Flow through Porous Media	180
	References	182
	Further Reading	183
	Problems	183
CHAPTER 7	TURBULENT FLOW IN PIPES	185
7.1	Introduction	185
7.2	Head Lost to Friction in a Pipe	185
7.3	Variation of Friction Factor	187
7.4	Friction in Non-Circular Conduits	192
7.5	Other Head Losses in Pipes	193
7.5.1	Loss at Abrupt Enlargement	194
7.5.2	Loss at Abrupt Contraction	195
7.5.3	Diffusers	197
7.5.4	Losses in Bends	199
7.5.5	Losses in Pipe Fittings	200
7.6	Total Head and Pressure Lines	201
7.7	Combinations of Pipes	205
7.7.1	Pipes in Series	205
7.7.2	Pipes in Parallel	205
7.7.3	Branched Pipes	206
7.7.4	Pipe Networks	208
7.7.5	Pipes with Side Tappings	209
7.8	Conditions near the Entry to the Pipe	209

7.9	Quasi-Steady Flow in Pipes	211
	References	213
	Further Reading	213
	Problems	214
CHAPTER 8	PHYSICAL SIMILARITY	217
8.1	Introduction	217
8.2	Dimensional Analysis	217
8.3	The Concept of Physical Similarity	218
8.4	Types of Physical Similarity	219
8.4.1	Geometric Similarity	219
8.4.2	Kinematic Similarity	220
8.4.3	Dynamic Similarity	221
8.5	Ratios of Forces Arising in Dynamic Similarity	222
8.5.1	Dynamic Similarity of Flow with Viscous Forces Acting	223
8.5.2	Dynamic Similarity of Flow with Gravity Forces Acting	224
8.5.3	Dynamic Similarity of Flow with Surface Tension Forces Acting	225
8.5.4	Dynamic Similarity of Flow with Elastic Forces Acting	226
8.5.5	Other Types of Dynamic Similarity	227
8.6	The Application of Dynamic Similarity	228
8.7	Ship Resistance	231
	Reference	235
	Further Reading	235
	Problems	236
CHAPTER 9	THE FLOW OF AN IDEAL FLUID	238
9.1	Introduction	238
9.2	The Stream Function	239
9.3	Circulation and Vorticity	241
9.4	Velocity Potential	244
9.5	Flow Nets	245
9.6	Separation	247
9.7	Combining Flow Patterns	249
9.8	Basic Patterns of Flow	250
9.8.1	Rectilinear Flow	250
9.8.2	Flow from a Line Source	251
9.8.3	Flow to a Line Sink	252
9.8.4	Irrotational Vortex	252
9.8.5	Forced (Rotational) Vortex	256
9.9	Combinations of Basic Flow Patterns	257
9.9.1	Uniform Rectilinear Flow and Line Source	257
9.9.2	Source and Sink of Numerically Equal Strength	258
9.9.3	Source and Sink of Numerically Equal Strength, combined with Uniform Rectilinear Flow	259
9.9.4	The Doublet	260
9.9.5	Doublet and Uniform Rectilinear Flow	260
9.9.6	Doublet, Uniform Rectilinear Flow and Irrotational Vortex	263
9.9.7	Vortex Pair	266

9.9.8 Irrotational Vortex and Line Source (Spiral Vortex)	268
9.10 Elementary Aerofoil Theory	268
9.10.1 Definitions	268
9.10.2 Aerofoils of Infinite Span	269
9.10.3 Aerofoils of Finite Span	272
9.10.4 Induced Drag	273
References	275
Further Reading	275
Problems	276
CHAPTER 10 BOUNDARY LAYERS AND WAKES	279
10.1 Introduction	279
10.2 Description of the Boundary Layer	280
10.3 The Thickness of the Boundary Layer	282
10.4 The Momentum Equation Applied to the Boundary Layer	283
10.5 The Laminar Boundary Layer on a Smooth Flat Plate with Zero Pressure Gradient	286
10.6 The Turbulent Boundary Layer on a Smooth Flat Plate with Zero Pressure Gradient	289
10.7 Friction Drag for Laminar and Turbulent Boundary Layers Together	293
10.8 Effect of Pressure Gradient	295
10.8.1 Separation and Flow over Curved Surfaces	295
10.8.2 Pressure Drag	297
10.8.3 Profile Drag of 'Two-Dimensional' Bodies	301
10.8.4 Profile Drag of 'Three-Dimensional' Bodies	304
10.8.5 Separation from an Aerofoil	306
10.9 Boundary Layer Control	310
10.10 Effect of Compressibility on Drag	311
10.11 Distribution of Velocity in Turbulent Flow	313
10.11.1 Velocity Distribution in Smooth Pipes and over Smooth Plates	314
10.11.2 Friction Factor for Smooth Pipes	317
10.11.3 Velocity Distribution and Friction Factor for Rough Pipes	318
10.11.4 Universal Features of the Velocity Distribution in Turbulent Flow	321
10.12 Free Turbulence	321
References	323
Further Reading	323
Problems	323
CHAPTER 11 FLOW WITH A FREE SURFACE	325
11.1 Introduction	325
11.2 Types of Flow in Open Channels	326
11.3 Bernoulli's Equation applied to Flow in Open Channels	327
11.3.1 Energy Gradient	329
11.4 Steady Uniform Flow—The Chézy Equation	330
11.5 The Boundary Layer in Open Channels	333
11.6 Optimum Shape of Cross-Section	335
11.7 Flow in Closed Conduits only Partly Full	336

11.8	Simple Waves and Surges in Open Channels	337
11.9	Specific Energy and Alternative Depths of Flow	340
11.9.1	The Use of the Specific-Energy Curve in Dimensionless Form	344
11.10	The Hydraulic Jump	345
11.10.1	The Force Applied to Obstacles in a Stream	349
11.11	The Occurrence of Critical Conditions	350
11.11.1	The Broad-crested Weir	351
11.11.2	Drowned Weir and Free Outfall	355
11.11.3	Rapid Flow Approaching a Weir or Other Obstruction	356
11.11.4	The Venturi Flume	358
11.12	Gradually Varied Flow	360
11.12.1	The Equations of Gradually Varied Flow	362
11.12.2	Classification of Surface Profiles	366
11.13	Conclusion	368
	References	368
	Further Reading	368
	Problems	369
CHAPTER 12	FLOW WITH APPRECIABLE CHANGES OF DENSITY	371
12.1	Introduction	371
12.2	Thermodynamic Concepts	371
12.3	Energy Equation with Variable Density: Static and Stagnation Temperature	374
12.4	Elastic Waves	376
12.4.1	The Mach Cone	379
12.4.2	Propagation of Finite Waves	381
12.5	Shock Waves	381
12.5.1	Normal Shock Waves	382
12.5.2	Oblique Shock Waves	386
12.5.3	Reflection and Intersection of Oblique Shock Waves	389
12.6	Supersonic Flow round a Corner	391
12.6.1	Supersonic Flow over a Concave Boundary	395
12.6.2	Supersonic Flow between Two Boundaries	395
12.7	The Pitot Tube in Flow with Variable Density	395
12.8	One-Dimensional Flow with Negligible Friction	398
12.9	High-Speed Flow past an Aerofoil	403
12.10	Flow with Variable Density in Pipes of Constant Cross-section	407
12.10.1	Adiabatic Flow in a Pipe	408
12.10.2	Isothermal Flow in a Pipe	414
12.10.3	Laminar Flow in a Circular Pipe	416
12.11	Analogy between Flow with Variable Density and Flow with a Free Surface	417
	References	418
	Further Reading	418
	Problems	419
CHAPTER 13	UNSTEADY FLOW	421
13.1	Introduction	421
13.2	Inertia Pressure	421

13.3	Water Hammer	424
13.3.1	The Velocity and Magnitude of Pressure Waves	426
13.3.2	The Reflection of Waves	430
13.3.3	Slow Closure of the Valve	434
13.4	Surge Tanks	439
	References	442
	Further Reading	442
	Problems	442
CHAPTER 14	THE PRINCIPLES OF FLUID MACHINES	444
14.1	Introduction	444
14.2	Reciprocating Pumps	445
14.3	Rotodynamic Machines	449
14.3.1	Types of Turbine	449
14.3.2	The Pelton Wheel	450
14.3.3	Reaction Turbines	456
14.3.4	Basic Equations for Rotodynamic Machinery	460
14.3.5	Similarity Laws and Specific Speed	464
14.3.6	Cavitation	469
14.3.7	The Performance Characteristics of Turbines	473
14.4	Rotodynamic Pumps	474
14.4.1	Centrifugal Pumps	475
14.4.2	The Basic Equations applied to Centrifugal Pumps	477
14.4.3	The Effects of Non-uniform Velocity Distribution	481
14.4.4	Axial- and Mixed-Flow Pumps	483
14.4.5	Similarity Laws and Specific Speed for Pumps	484
14.4.6	Cavitation in Centrifugal Pumps	485
14.4.7	The Performance Characteristics of Pumps	486
14.5	Hydrodynamic Transmissions	487
14.5.1	The Fluid Coupling	488
14.5.2	The Torque Converter	490
14.6	The Effect of Size on the Efficiency of Fluid Machines	492
	References	493
	Further Reading	493
	Problems	494
APPENDIX 1	FIRST AND SECOND MOMENTS AND CENTROIDS	498
A1.1	First Moments	498
A1.2	Second Moments	499
APPENDIX 2	MEASUREMENTS AND FLOW VISUALIZATION	501
A2.1	Measurement of Velocity	501
A2.2	Measurement of Discharge	503
A2.3	Measurement of Surface Elevation	504
A2.4	Measurement of Flow Direction	505
A2.5	Flow Visualization	506
	Further Reading	508
APPENDIX 3	TABLES OF GAS FLOW FUNCTIONS	509
A3.1	Plane Normal Shock	509
A3.2	Isentropic Flow	512

A3.3 Adiabatic Flow with Friction in Duct of Constant Cross-section	514
APPENDIX 4 ALGEBRAIC SYMBOLS	517
INDEX	523