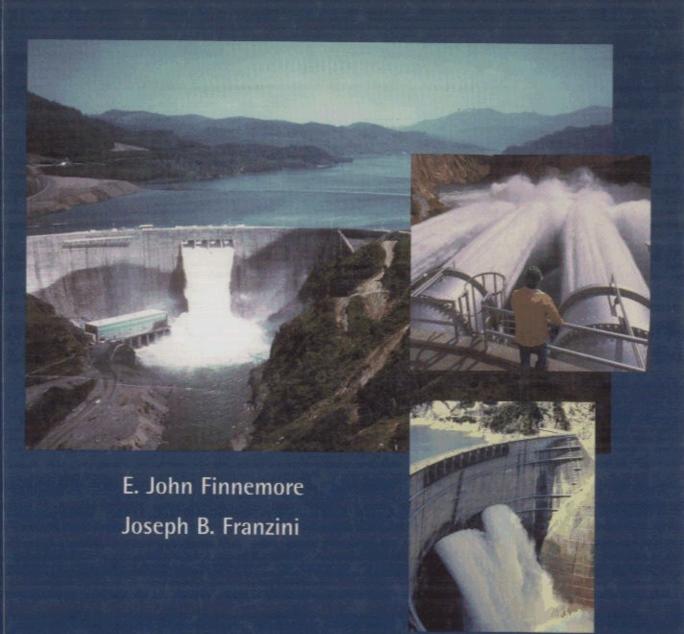
Fluid Mechanics

with Engineering Applications

Tenth Edition



Contents

All Directions 45

Preface xv		3.2	Variation of Pressure in a
List of Symbols xix			Static Fluid 46
List of	Abbreviations xxv	3.3	Pressure Expressed in Height of Fluid 50
Chap	ter 1 Introduction 1	3.4 3.5	Absolute and Gage Pressures 53 Measurement of Pressure 55
1.1	Scope of Fluid Mechanics 1	3.6	Force on a Plane Area 66
1.2	Historical Sketch of the Development	3.7	Center of Pressure 68
	of Fluid Mechanics 2	3.8	Force on a Curved Surface 77
1.3	The Book, Its Contents, and How to	3.9	Buoyancy and Stability of
	Best Study Fluid Mechanics 3		Submerged and Floating
1.4	Approach to Problem Solving 4		Bodies 81
1.5	Dimensions and Units 6	3.10	Liquid Masses Subjected to
			Acceleration 88
CI.			Problems 92
Chap	ter 2 Properties of Fluids 13		
2.1	Distinction Between a Solid	Chap	ter 4 Basics of Fluid Flow 97
	and a Fluid 13	4.1	Types of Flow 97
2.2	Distinction Between a Gas	4.2	Laminar and Turbulent
	and a Liquid 13		Flow 98
2.3	Density, Specific Weight, Specific	4.3	Steady Flow and Uniform
	Volume, and Specific Gravity 14		Flow 101
2.4	Compressible and Incompressible	4.4	Path Lines, Streamlines, and
	Fluids 16		Streak Lines 102
2.5	Compressibility of Liquids 17	4.5	Flow Rate and Mean Velocity 103
2.6	Specific Weight of Liquids 19	4.6	Fluid System and Control
2.7	Property Relations for		Volume 106
2.0	Perfect Gases 22	4.7	Equation of Continuity 108
2.8	Compressibility of Perfect Gases 25	4.8	One-, Two-, and
2.9	Standard Atmosphere 27		Three-Dimensional Flow 110
	Ideal Fluid 29	4.9	The Flow Net 111
	Viscosity 29	4.10	Use and Limitations of the
	Surface Tension 37		Flow Net 114
2.13	Vapor Pressure of Liquids 40	4.11	Frame of Reference in
	Problems 41		Flow Problems 117
	•	4.12	Velocity and Acceleration in
CI.	4 0 101 11 014 41 42		Steady Flow 117
Chap	eter 3 Fluid Statics 45	4.13	Velocity and Acceleration in
3.1	Pressure at a Point the Same in		Unsteady Flow 121

Problems 124

X Contents

A	Contents		
Chap	ter 5 Energy in Steady Flow 127	6.7	Moving Vanes: Relation Between Absolute and Relative Velocities 200
5.1	Energies of a Flowing Fluid 127	6.8	Force of a Jet on One or More Moving
5.2	Equation for Steady Motion of an Ideal		Vanes or Blades 201
	Fluid Along a Streamline, and Bernoulli's Theorem 131	6.9	Reaction of a Jet 206
5.3	Equation for Steady Motion of a Real		Jet Propulsion 210
5.5	Fluid Along a Streamline 135	6.11	Rotating Machines: Continuity, Relative
5.4	Pressure in Fluid Flow 138		Velocities, Torque 212
5.5	General Energy Equation for Steady	6.12	Head Equivalent of Mechanical
5,5	Flow of Any Fluid 140		Work 219
5.6	Energy Equations for Steady Flow of		Flow Through a Rotating Channel 219
- 70	Incompressible Fluids,		Reaction with Rotation 220
	Bernoulli's Theorem 143	6.15	Momentum Principle Applied to
5.7	Energy Equation for Steady Flow of		Propellers and Windmills 222
	Compressible Fluids 147		Problems 226
5.8	Head 150		
5.9	Power Considerations in Fluid	Chan	ter 7 Similitude and Dimensional
	Flow 150	Спар	Analysis 232
	Cavitation 154		•
5.11	Definition of Hydraulic Grade Line and	7.1	Definition and Uses of Similitude 232
	Energy Line 158	7.2	Geometric Similarity 232
5.12	Loss of Head at Submerged	7.3	Kinematic Similarity 233
	Discharge 160	7.4	Dynamic Similarity 234
5.13	Application of Hydraulic Grade Line	7.5	Scale Ratios 241
	and Energy Line 161	7.6	Comments on Models 243
5.14	Method of Solution of Liquid Flow	7.7	Dimensional Analysis 245
	Problems 165		Problems 252
	Jet Trajectory 169		
	Flow in a Curved Path 172	Chan	tar & Staady Incompressible Flow
	Forced or Rotational Vortex 173	Chap	ter 8 Steady Incompressible Flow in Pressure Conduits 255
5.18	Free or Irrotational Vortex 176		in Tressure Conduits 233
	Problems 179	8.1	Laminar and Turbulent Flow 255
		8.2	Critical Reynolds Number 256
Chan	ter 6 Momentum and Forces in	8.3	Hydraulic Radius, Hydraulic
O	Fluid Flow 185	_	Diameter 258
		8.4	Friction Head Loss in Conduits of
6.1	Development of the Momentum		Constant Cross Section 258
	Principle 185	8.5	Friction in Circular Conduits 261
6.2	Navier-Stokes Equations 188	8.6	Friction in Noncircular Conduits 263
6.3	Momentum Correction Factor 189	8.7	Laminar Flow in Circular Pipes 264
6.4	Applications of the Momentum	8.8	Entrance Conditions in Laminar
~ ~	Principle 190	0.0	Flow 265
6.5	Force on Pressure Conduits 193	8.9	Turbulent Flow 268
6.6	Force of a Free Jet on a Stationary	8.10	Viscous Sublayer in Turbulent
	Vane or Blade 198		Flow 271

8.11	Velocity Profile in Turbulent Flow 276	9.6	Boundary-Layer Separation and
8.12	Pipe Roughness 280		Pressure Drag 372
	Chart for Friction Factor 282	9.7	Drag on Three-Dimensional Bodies
	Single-Pipe Flow: Solution Basics 285		(Incompressible Flow) 374
8.15	Single-Pipe Flow: Solution by Trials 287	9.8	Drag on Two-Dimensional Bodies
8 16	Single-Pipe Flow: Direct Solutions 293	9.9	(Incompressible Flow) 382 Lift and Circulation 385
	Single-Pipe Flow: Automated		
0.17	Solutions 296		Ideal Flow About a Cylinder 387 Lift of an Airfoil 390
8 18	Empirical Equations for Single-Pipe		
0.10	Flow 298	3.12	Induced Drag on Airfoil of Finite Length 392
8.19	Nonrigorous Head-Loss	013	Lift and Drag Diagrams 395
	Equations 300		Effects of Compressibility on Drag
8.20	Minor Losses in Turbulent Flow 301	J.1.T	and Lift 399
	Loss of Head at Entrance 302	915	Concluding Remarks 401
	Loss of Head at Submerged	7.10	
	Discharge 303		Problems 402
8.23	Loss Due to Contraction 305		
	Loss Due to Expansion 307	Chap	oter 10 Steady Flow in Open
	Loss in Pipe Fittings 312		Channels 407
	Loss in Bends and Elbows 312	10.1	Open Channels 407
8.27	Single-Pipe Flow with Minor	10.2	Uniform Flow 409
	Losses 315	10.3	Solution of Uniform Flow
8.28	Pipeline with Pump or Turbine 321	10.0	Problems 414
	Branching Pipes 326	10.4	Velocity Distribution in Open
	Pipes in Series 333		Channels 419
8.31	Pipes in Parallel 336	10.5	"Wide and Shallow" Flow 421
8.32	Pipe Networks 339	10.6	Most Efficient Cross Section 422
8.33	Further Topics in Pipe Flow 343	10.7	Circular Sections Not Flowing
	Problems 344		Full 426
	.	10.8	Laminar Flow in Open Channels 429
Chap	tar 0 Farans on Immoread	10.9	Specific Energy and Alternate Depths
Спар	ter 9 Forces on Immersed Bodies 356		of Flow in Rectangular Channels 431
		10.10	Subcritical and Supercritical Flow 436
9.1	Introduction 356		Critical Depth in Nonrectangular
9.2	Friction Drag of Boundary Layer—		Channels 438
	Incompressible Flow 358	10.12	Occurrence of Critical Depth 441
9.3	Laminar Boundary Layer for		Humps and Contractions 442
	Incompressible Flow Along a Smooth		Nonuniform, or Varied, Flow 448
	Flat Plate 360		Energy Equation for Gradually Varied
9.4	Turbulent Boundary Layer for		Flow 449
	Incompressible Flow Along a Smooth	10.16	Water-Surface Profiles in Gradually
	Flat Plate 365		Varied Flow (Rectangular
9.5	Friction Drag for Incompressible Flow		Channels) 452
	Along a Smooth Flat Plate with a	10.17	Examples of Water-Surface
	Transition Regime 369		Profiles 456

XII Contents

10.18	The Hydraulic Jump 460	12.5	Velocity of Pressure Wave in	
	Location of Hydraulic Jump 465		Pipes 558	
	Velocity of Gravity Waves 468	12.6	Water Hammer 559	
	Flow Around Channel Bends 471	12.7	Surge Tanks 569	
	Transitions 474		Problems 574	
	Hydraulics of Culverts 476			
10.24	Further Topics in Open-Channel	Chan	ter 13 Steady Flow of Compressible	
	Flow 480	Спар	Fluids 580	
	Problems 481	10.4		
			Thermodynamic Considerations 580	
Chap	ter 11 Fluid Measurements 491	13.2	Fundamental Equations Applicable to the Flow of Compressible	
11.1	Measurement of Fluid Properties 491		Fluids 584	
11.2	Measurement of Static	13.3	Speed of Sound 585	
	Pressure 495	13.4	Adiabatic Flow (With or Without	
11.3	Measurement of Velocity with		Friction) 588	
	Pitot Tubes 496	13.5	Stagnation Properties 589	
11.4	Measurement of Velocity by Other	13.6	Isentropic Flow 593	
	Methods 500	13.7	Effect of Area Variation on	
11.5	Measurement of Discharge 503		One-Dimensional Compressible	
11.6	Orifices, Nozzles, and Tubes 505	4.	Flow 594	
11.7	Venturi Meter 515	13.8	Compressible Flow Through a	
11.8	Flow Nozzle 519	4.0	Converging Nozzle 596	
11.9	Orifice Meter 522	13.9	Isentropic Flow Through a	
11.10	Flow Measurement of	4	Converging-Diverging Nozzle 600	
11 11	Compressible Fluids 524		One-Dimensional Shock Wave 603	
	Thin-Plate Weirs 527		The Oblique Shock Wave 607	
11.12	Streamlined Weirs and Free		Isothermal Flow 609	
11 10	Overfall 533	13.13	Isothermal Flow in a Constant-Area	
	Overflow Spillway 536 Sluice Gate 538	10 14	Duct 610	
		13.14	Adiabatic Flow in a Constant-Area	
11.13	Measurement of Liquid-Surface Elevation 540	12 15	Duct 614	
11 16	Other Methods of Measuring		Comparison of Flow Types 618	
11.10	Discharge 540	15.10	Concluding Remarks 619	
	Problems 541		Problems 619	
	Flublems 541	C 1	4 14 13170	
Chapter 12 Unsteady-Flow		Cnap	ter 14 Ideal Flow Mathematics 622	
Спар	Problems 546		Wrathematics 022	
		14.1	Differential Equation of	
12.1	Introduction 546		Continuity 622	
12.2	Discharge with Varying	14.2	Irrotational Flow 625	
10.0	Head 546	14.3	Circulation and Vorticity 627	
12.3	Unsteady Flow of Incompressible	14.4	The Stream Function 629	
10.4	Fluids in Pipes 550 Approach to Steady Flow 554	14.5	Basic Flow Fields 631 Velocity Potential 635	
1/4	ADDIOACH TO STEADY FLOW 134	1/4 10	velocity Potennal 633	

	٠		٠
w	1	•	п
ж.			

14.7	Orthogonality of Streamlines and Equipotential Lines 636	16.4	Head on an Impulse Turbine and Efficiency 691
14.8	Flow Through Porous Media 639	16.5	Nozzles for Impulse
	Problems 642		Turbines 695
		16.6	Reaction Turbines 697
Chap	ter 15 Hydraulic Machinery—	16.7	Action of the Reaction
	Pumps 647		Turbine 701
15.1	Description of Centrifugal and	16.8	Draft Tubes and Effective Head on
13.1	Axial-Flow Pumps 647		Reaction Turbines 702
15.2	Head Developed by a Pump 651	16.9	Efficiency of Turbines 706
		16.10	
	•	16.11	· · · · · · · · · · · · · · · · · · ·
15.5		4 / 4 /	
156	-		
15.0			
15.7			
		16.13	
			Problems 722
	_	Anr	endixes
			-
15.14	·		
	•		
	2 I OMACINE W/		
Chapter 16 Hydraulic Machinery—			v
K	Turbines 685	- 41	THE POLICE OF LANCE CORES OF THE POLICE OF T
16.1	Hydraulic Turbines 685	Inda	ex 777
		ANIM	/2k
15.3 15.4 15.5 15.6 15.7 15.8 15.9 15.10 15.11 15.12 15.13	Pump Efficiency 652 Similarity Laws for Pumps 652 Performance Characteristics of Pumps at Constant Speed 655 Performance Characteristics at Different Speeds and Sizes 658 Operating Point of a Pump 660 Specific Speed of Pumps 662 Peripheral-Velocity Factor 665 Cavitation in Pumps 666 Viscosity Effect 671 Selection of Pumps 671 Pumps Operating in Series and in Parallel 675 Pump Installations 677 Problems 679 ter 16 Hydraulic Machinery—	16.11 16.12 16.13 16.14 16.15 App A B B B C B B B B B B B B B B	cendixes Fluid and Geometric Properties 729 Equations in Fluid Mechanics 740 Programming and Computer Applications 745 Examples of Using Solvers 754 References 764 Answers to Exercises 769