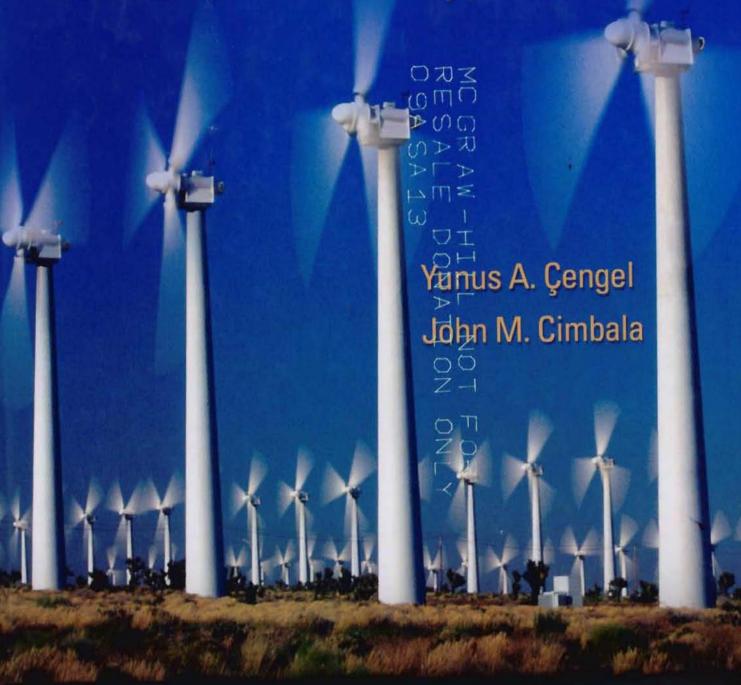
Second Edition

Fluid Mechanics

Fundamentals and Applications



CONTENTS

	Preface xv		Application Spotlight: What Nuclear Blasts and Raindrops Have in Common 32
C H	APTER ONE		Problems 33
INTRO	DDUCTION AND BASIC CONCEPTS 1		
1–1	Introduction 2 What Is a Fluid? 2		APTER TWO ERTIES OF FLUIDS 37
1–2	Application Areas of Fluid Mechanics 4 The No-Slip Condition 6	2–1	Introduction 38 Continuum 38
1-3	A Brief History of Fluid Mechanics 7 Classification of Fluid Flows 9	2–2	Density and Specific Gravity 39 Density of Ideal Gases 40
1–4		2–3	Vapor Pressure and Cavitation 41
	Viscous versus Inviscid Regions of Flow 10 Internal versus External Flow 10 Compressible versus Incompressible Flow 10	2-4	Energy and Specific Heats 43
	Laminar versus Turbulent Flow 11 Natural (or Unforced) versus Forced Flow 11	2–5	Compressibility and Speed of Sound 44
	Steady versus Unsteady Flow 12 One-, Two-, and Three-Dimensional Flows 13		Coefficient of Compressibility 44. Coefficient of Volume Expansion •46
1–5	System and Control Volume 14	2–6	Speed of Sound and Mach Number 48 Viscosity 50
1–6	Importance of Dimensions and Units 15	2- 6 2-7	Surface Tension and Capillary Effect 55
	Some SI and English Units 17 Dimensional Homogeneity 19 Unity Conversion Ratios 20		Capillary Effect 58 Summary 61
1–7	Mathematical Modeling of Engineering Problems 21		Application Spotlight: Cavitation 62 References and Suggested Reading 63
	Modeling in Engineering 22		Problems 63
1–8	Problem-Solving Technique 23		
	Step 1: Problem Statement 24 Step 2: Schematic 24 Step 3: Assumptions and Approximations 24 Step 4: Physical Laws 24 Step 5: Properties 24 Step 6: Calculations 25 Step 7: Reasoning, Verification, and Discussion 25		APTER THREE SURE AND FLUID STATICS 73
		3–1	Pressure 74
1–9	Engineering Software Packages 25 Engineering Equation Solver (EES) 26 FlowLab 27		Pressure at a Point 75 Variation of Pressure with Depth 76
		3–2	Pressure Measurement Devices 79
1–10	Accuracy, Precision, and Significant Digits 28		The Barometer 79 The Manometer 82 Other Pressure Measurement Devices 86
	Summary 31	3–3	Introduction to Fluid Statics 87

References and Suggested Reading 31

3–4	Hydrostatic Forces on Submerged Plane Surfaces 88		APTER FIVE	
	Special Case: Submerged Rectangular Plate 90 Hydrostatic Forces on Submerged Curved Surfaces 93	MASS, BERNOULLI, AND ENERGY EQUATIONS 183		
3–5				
3-6	Buoyancy and Stability 97	5–1	Introduction 184	
•	Stability of Immersed and Floating Bodies 100 Fluids in Rigid-Body Motion 102 Special Case 1: Fluids at Rest 104 Special Case 2: Free Fall of a Fluid Body 104 Acceleration on a Straight Path 105 Rotation in a Cylindrical Container 107		Conservation of Mass 184 The Linear Momentum Equation 184 Conservation of Energy 184	
3–7				
- '		5–2 5–3	Conservation of Mass 185	
			Mass and Volume Flow Rates 185 Conservation of Mass Principle 187 Moving or Deforming Control Volumes 189 Mass Balance for Steady-Flow Processes 189	
	Summary 110 References and Suggested Reading 111		Special Case: Incompressible Flow 190	
	Problems 111		Mechanical Energy and Efficiency 192	
		5–4	The Bernoulli Equation 197	
CHAPTER FOUR FLUID KINEMATICS 131			Acceleration of a Fluid Particle 197 Derivation of the Bernoulli Equation 198 Force Balance across Streamlines 200 Unsteady, Compressible Flow 200 Static, Dynamic, and Stagnation Pressures 200	
4–1	Lagrangian and Eulerian Descriptions 132 Acceleration Field 134 Material Derivative 137		Limitations on the Use of the Bernoulli Equation 202 Hydraulic Grade Line (HGL) and Energy Grade Line (EGL) 203 Applications of the Bernoulli Equation 205	
4–2	Flow Patterns and Flow Visualization 139	55	General Energy Equation 212	
4-2	Streamlines and Streamtubes 139 Pathlines 140 Streaklines 142 Timelines 144 Refractive Flow Visualization Techniques 145 Surface Flow Visualization Techniques 146		Energy Transfer by Heat, Q 213 Energy Transfer by Work, W 213	
		5–6	Energy Analysis of Steady Flows 217	
			Special Case: Incompressible Flow with No Mechanical Work Devices and Negligible Friction 219	
4–3	Plots of Fluid Flow Data 146		Kinetic Energy Correction Factor, α 219	
	Profile Plots 147 Vector Plots 147 Contour Plots 148		Summary 226 References and Suggested Reading 227 Problems 228	
4-4	Other Kinematic Descriptions 149			
	Types of Motion or Deformation of Fluid Elements 149			
4–5	Vorticity and Rotationality 154	СН	IAPTER SIX	
	Comparison of Two Circular Flows 157	MON	MENTUM ANALYSIS OF FLOW	
4–6	The Reynolds Transport Theorem 158		TEMS 239	
	Alternate Derivation of the Reynolds Transport Theorem 163 Relationship between Material Derivative and RTT 165	6–1	Newton's Laws 240	

6-2

Summary 166

Problems 168

Application Spotlight: Fluidic Actuators 167

References and Suggested Reading 168

Choosing A Control Volume 241

Forces Acting On A Control Volume 242

8-1

8-2

Introduction 338

Reynolds Number 340

Laminar and Turbulent Flows 339

6-4	The Linear Momentum Equation 245	8–3	The Entrance Region 341
	Special Cases 247 Momentum-Flux Correction Factor, β 247 Steady Flow 249	8-4	Entry Lengths 342
			Laminar Flow In Pipes 343
6–5	Flow with No External Forces 250 Review of Rotational Motion and Angular Momentum 259		Pressure Drop and Head Loss 345 Effect of Gravity on Velocity and Flow Rate in Laminar Flow 347 Laminar Flow in Noncircular Pipes 348
6–6	The Angular Momentum Equation 261 Special Cases 263 Flow with No External Moments 264 Radial-Flow Devices 265 Summary 269 References and Suggested Reading 270 Problems 270	8–5	Turbulent Flow In Pipes 351
			Turbulent Shear Stress 353 Turbulent Velocity Profile 354 The Moody Chart and the Colebrook Equation 357
		8–6	Types of Fluid Flow Problems 359 Minor Losses 364
	Flublettis 270		
СН	APTER SEVEN	8–7	Piping Networks and Pump Selection 371
DIME	NSIONAL ANALYSIS AND		Series and Parallel Pipes 371 Piping Systems with Pumps and Turbines 373
MODE		8–8	Flow Rate and Velocity Measurement 381
7-1 7-2 7-3 7-4	Dimensions and Units 284 Dimensional Homogeneity 285 Nondimensionalization of Equations 286 Dimensional Analysis and Similarity 291 The Method of Repeating Variables and The Buckingham Pi Theorem 295 Historical Spotlight: Persons Honored by Nondimensional Parameters 303 Experimental Testing, Modeling, and Incomplete Similarity 311 Setup of an Experiment and Correlation of Experimental Data 311 Incomplete Similarity 312 Wind Tunnel Testing 312		Pitot and Pitot-Static Probes 381 Obstruction Flowmeters: Orifice, Venturi, and Nozzle Meters 382 Positive Displacement Flowmeters 386 Turbine Flowmeters 387 Variable-Area Flowmeters (Rotameters) 388 Ultrasonic Flowmeters 389 Electromagnetic Flowmeters 391 Vortex Flowmeters 392 Thermal (Hot-Wire and Hot-Film) Anemometers 392 Laser Doppler Velocimetry 394 Particle Image Velocimetry 396 Application Spotlight: How Orifice Plate Flowmeters Work, or Do Not Work 399 Summary 400 References and Suggested Reading 401 Problems 402
	Flows with Free Surfaces 315	СН	APTER NINE
	Application Spotlight: How a Fly Flies 318 Summary 319 References and Suggested Reading 319 Problems 319	DIFFERENTIAL ANALYSIS OF FLUID FLOW 419	
		9-1	Introduction 420
СН	APTER EIGHT	9–2	Conservation of Mass—The Continuity Equation 420
INTER	RNAL FLOW 337		Derivation Using the Divergence Theorem 421 Derivation Using an Infinitesimal Control Volume 422 Alternative Form of the Continuity Equation 425

9-3

The Stream Function in Cartesian Coordinates 432 The Stream Function in Cylindrical Coordinates 439

426

Continuity Equation in Cylindrical Coordinates Special Cases of the Continuity Equation 426

The Stream Function 432

Irrotational Flows Formed by Superposition 521

10–6 The Boundary Layer Approximation 530

The Boundary Layer Equations 535
The Boundary Layer Procedure 540

	Derivation Using an Infinitesimal Control Volume 442 Alternative Form of Cauchyis Equation 445 Derivation Using Newton's Second Law 445		Displacement Thickness 544 Momentum Thickness 547 Turbulent Flat Plate Boundary Layer 548 Reguladory Layers with Procesure Cradinate 554
)- 5	The Navier–Stokes Equation 446 Introduction 446		Boundary Layers with Pressure Gradients 554 The Momentum Integral Technique for Boundary Layers 559
	Newtonian versus Non-Newtonian Fluids 447 Derivation of the Navier–Stokes Equation for Incompressible, Isothermal Flow 448 Continuity and Navier–Stokes Equations in Cartesian Coordinates 450 Continuity and Navier–Stokes Equations in Cylindrical Coordinates 451	CH	Summary 567 References and Suggested Reading 568 Application Spotlight: Droplet Formation 569 Problems 570 A P T E R E L V E N
)- 6	Differential Analysis of Fluid Flow Problems 452		RNAL FLOW: DRAG AND LIFT 583
	Calculation of the Pressure Field for a Known Velocity Field 452 Exact Solutions of the Continuity and Navier–Stokes Equations 457	11-1	Introduction 584
		11–2	Drag and Lift 586
		11–3	Friction and Pressure Drag 590
	Summary 475 References and Suggested Reading 476 Problems 476		Reducing Drag by Streamlining 591 Flow Separation 592
		11-4	Drag Coefficients of Common Geometries 593
СН	APTER TEN		Biological Systems and Drag 597 Drag Coefficients of Vehicles 598 Superposition 599
PPR	OXIMATE SOLUTIONS OF THE	11–5	Parallel Flow Over Flat Plates 601
	ER-STOKES EQUATION 491		Friction Coefficient 603
		11–6	Flow Over Cylinders and Spheres 606
0–1	Introduction 492		Effect of Surface Roughness 608
0–2	Nondimensionalized Equations	11–7	Lift 610
	of Motion 493		Finite-Span Wings and Induced Drag 614 Lift Generated by Spinning 615
0–3	The Creeping Flow Approximation 496		Summary 619
	Drag on a Sphere in Creeping Flow 499		References and Suggested Reading 620 Application Spotlight: Drag Reduction 621 Problems 622
	Approximation for Inviscid Regions of Flow 501		
	Derivation of the Bernoulli Equation in Inviscid Regions of Flow 502	СU	ADTED TWEIVE

COMPRESSIBLE FLOW

12–1 Stagnation Properties 636

12–2 One-Dimensional Isentropic Flow 639

Variation of Fluid Velocity with Flow Area 642

635

The Compressible Stream Function 440

Derivation Using the Divergence Theorem 441

10–5 The Irrotational Flow Approximation 505

Derivation of the Bernoulli Equation in Irrotational

Two-Dimensional Irrotational Regions of Flow 510

Superposition in Irrotational Regions of Flow 514 Elementary Planar Irrotational Flows 514

Continuity Equation 505 Momentum Equation 507

Regions of Flow 507

Cauchy's Equation 441

The Differential Linear Momentum Equation—

Liquid Surface Profiles in Open Channels, y(x) 725

Some Representative Surface Profiles 728 Numerical Solution of Surface Profile 730

13–8 Rapidly Varied Flow and The Hydraulic

Jump 733

	Property Relations for Isentropic Flow of Ideal Gases 643	13–9	Flow Control and Measurement 737	
12-3	Isentropic Flow Through Nozzles 646		Underflow Gates 738	
	Converging Nozzles 646 Converging–Diverging Nozzles 651		Overflow Gates 740	
12-4	Shock Waves and Expansion Waves 655		Summary 747 References and Suggested Reading 748	
-	Normal Shocks 655		Problems 748	
	Oblique Shocks 661		ADTED FOURTERN	
12-5	Prandtl–Meyer Expansion Waves 665 Duct Flow With Heat Transfer and Negligible		APTER FOURTEEN	
12-5	Friction (Rayleigh Flow) 669	TURB	TURBOMACHINERY 761	
	Property Relations for Rayleigh Flow 675	14–1	Classifications and Terminology 762	
10.6	Choked Rayleigh Flow 676		Pumps 764	
12-0	Adiabatic Duct Flow With Friction (Fanno Flow) 678	17-2	Pump Performance Curves and Matching a Pump	
	Property Relations for Fanno Flow 681		to a Piping System 765	
	Choked Fanno Flow 684		Pump Cavitation and Net Positive Suction Head 771 Pumps in Series and Parallel 774	
	Application Spotlight: Shock-Wave/		Positive-Displacement Pumps 777	
	Boundary-Layer Interactions 688		Dynamic Pumps 780 Centrifugal Pumps 780	
	Summary 689 References and Suggested Reading 690 Problems 690	14.0	Axial Pumps 790	
		14–3	Pump Scaling Laws 799	
			Dimensional Analysis 799 Pump Specific Speed 801	
C H	APTER THIRTEEN		Affinity Laws 803	
OPEN	-CHANNEL FLOW 701	14-4	Turbines 807	
13_1	Classification of Open-Channel Flows 702		Positive-Displacement Turbines 808 Dynamic Turbines 808	
10-1	Uniform and Varied Flows 702		Impulse Turbines 809 Reaction Turbines 811	
	Laminar and Turbulent Flows in Channels 703		Gas and Steam Turbines 822	
13–2	Froude Number and Wave Speed 705	14 5	Wind Turbines 822	
	Speed of Surface Waves 707	14-5	Turbine Scaling Laws 831	
13–3	Specific Energy 709		Dimensionless Turbine Parameters 831 Turbine Specific Speed 833	
13-4	Conservation of Mass and Energy		Application Spotlight: Rotary Fuel	
	Equations 712		Atomizers 837	
13–5	Uniform Flow in Channels 713		Summary 838 References and Suggested Reading 838	
	Critical Uniform Flow 715		Problems 839	
13_6	Superposition Method for Nonuniform Perimeters 716 Best Hydraulic Cross Sections 719			
13-0	Rectangular Channels 721	СН	APTER FIFTEEN	
	Trapezoidal Channels 721	INTR	ODUCTION TO COMPUTATIONAL FLUID	
13-7	Gradually Varied Flow 723	DYNA	AMICS 853	

15–1 Introduction and Fundamentals 854

Motivation 854

Equations of Motion 854