CONTENTS

Preface to the Second Edition xiii
Preface to the First Edition xv
To the Instructor xvii
List of Symbols xxi

Chapter 1 Introduction 1

Chapter 2 Conservation Principles 4
The Control Volume / Principle of Conservation of Mass / The Momentum Theorem / Principle of Conservation of Energy

Chapter 3 Fluid Stresses and Flux Laws 9
Viscous Fluid Stresses / Fourier's Law of Heat Conduction / Fick's Law of Diffusion / Dimensionless Groups of Transport Properties / Turbulent-Flow Transport Coefficients / References

Chapter 4 The Differential Equations of the Boundary Layer 17
The Concept of the Boundary Layer / The Continuity Equations / The Momentum Equations / The Mass Diffusion Equations / The Energy Equations / The Equations for a Turbulent Boundary Layer / Problems / References

Chapter 5 The Integral Equations of the Boundary Layer 45

The Momentum Integral Equation / The Displacement and Momentum Thickness / Alternative Forms of the Momentum Integral Equation / The Energy Integral Equation / The Enthalpy and Conduction Thicknesses / Alternative Forms of the Energy Integral Equation / Problems / Reference

Chapter 6 Momentum Transfer: Laminar Flow Inside Tubes 58

Fully Developed Laminar Flow in Circular Tubes / Fully Developed Laminar Flow in Other Cross-Sectional Shape Tubes / The Laminar Hydrodynamic Entry Length / Problems / References

Chapter 7 Momentum Transfer: The Laminar External Boundary Layer 70

Similarity Solutions: The Laminar Incompressible Boundary Layer with Constant Properties and Constant Free-Stream Velocity / Similarity Solutions for the Laminar Incompressible Boundary Layer for $u_\infty = Cx^m$ / Similarity Solutions for the Laminar Incompressible Boundary Layer for $v_0 \neq 0$ / Nonsimilar Momentum Boundary Layers / An Approximate Laminar Boundary-Layer Solution for Constant Free-Stream Velocity Developed from the Momentum Integral Equation / An Approximate Laminar Boundary-Layer Solution for Arbitrarily Varying Free-Stream Velocity over a Body of Revolution / Problems / References

Chapter 8 Heat Transfer: Laminar Flow inside Tubes 88

The Energy Differential Equations for Flow through a Circular Tube / The Circular Tube with Fully Developed Velocity and Temperature Profiles / The Concentric Circular-Tube Annulus with Fully Developed Velocity and Temperature Profiles, Asymmetric Heating / Solutions for Tubes of Noncircular Cross Section with Fully Developed Velocity and Temperature Profiles / Circular-Tube Thermal-Entry-Length Solutions / Thermal-Entry-Length Solutions for the Rectangular Tube and Annulus / The Effect of Axial Variation of the

Surface Temperature / The Effect of Axial Variation of Heat Flux / Combined Hydrodynamic and Thermal Entry Length / Problems / References

Chapter 9 Heat Transfer: The Laminar External Boundary Layer 133

Constant Free-Stream Velocity Flow along a Constant-Temperature Semi-Infinite Plate / Flow with $u_\infty = Cx^m$ along a Constant-Temperature Semi-Infinite Plate / Flow along a Constant-Temperature Semi-Infinite Plate with Injection or Suction / Nonsimilar Thermal Boundary Layers / Constant Free-Stream Velocity Flow along a Semi-Infinite Plate with Unheated Starting Length / Constant Free-Stream Velocity Flow along a Semi-Infinite Plate with Arbitrarily Specified Surface Temperature / Constant Free-Stream Velocity Flow along a Semi-Infinite Plate with Arbitrarily Specified Surface Heat Flux / Flow over a Constant-Temperature Body of Arbitrary Shape / Flow over a Body of Arbitrary Shape and Arbitrarily Specified Surface Temperature / Flow over Bodies with Boundary-Layer Separation / Problems / References

Chapter 10 Momentum Transfer: The Turbulent Momentum Boundary Layer 161

Transition of a Laminar Boundary Layer to a Turbulent Boundary Layer / The Qualitative Structure of the Turbulent Boundary Layer / The Concept of Eddy Diffusivity, Eddy Viscosity / The Prandtl Mixing-Length Theory / The Shear Stress Distribution Near a Wall / The Law of the Wall for the Case of $p^+ = 0.0$ and $v_0^+ = 0.0$ / An Approximate Solution to the Momentum Boundary Layer / Equilibrium Turbulent Boundary Layers / The Transpired Turbulent Boundary Layer / A Continuous Law of the Wall; the Van Driest Model / Summary of a Complete Mixing-Length Theory / The Effects of Surface Roughness / The Effects of Axial Pressure Gradient / High-Order Models of Turbulence / Problems / References

Chapter 11 Momentum Transfer: Turbulent Flow in Tubes 196

Fully Developed Flow in a Circular Tube / Other Flow Cross-Section Shapes / Effects of Surface Roughness / Problems / References

Chapter 12 Heat Transfer: The Turbulent Boundary Layer 504

The Concept of Eddy Diffusivity for Heat Transfer, Eddy Conductivity / The Reynolds Analogy / A Law of the Wall for the Thermal Boundary Layer / A Heat-Transfer Solution for Constant Free-Stream Velocity and Surface Temperature along a Semi-Infinite Plate / Constant Free-Stream Velocity Flow along a Semi-Infinite Plate with Unheated Starting Length / Constant Free-Stream Velocity Flow along a Semi-Infinite Plate with Arbitrarily Specified Surface Temperature / Constant Free-Stream Velocity Flow along a Semi-Infinite Plate with Arbitrarily Specified Heat Flux / Axisymmetric Body with Arbitrarily Varying Free-Stream Velocity and Surface Temperature / The Transpired Turbulent Boundary Layer / Film Cooling / The Turbulent Prandtl Number / Summary of a Complete Mixing-Length Theory / The Effects of Surface Roughness / Problems References

Chapter 13 Heat Transfer: Turbulent Flow Inside Tubes

Circular Tube with Fully Developed Velocity and Temperature Profiles, Constant Heat Rate, Prandtl Number near 1.00 / Circular Tube with Fully Developed Flow, Higher Prandtl Numbers / Very Low-Prandtl-Number Heat Transfer, Liquid Metals / Circular Tube, Fully Developed Profiles, Constant Surface Temperature / Effect of Peripheral Heat Flux Variation / Fully Developed Turbulent Flow between Parallel Planes and in Concentric Circular-Tube Annuli / Fully Developed Turbulent Flow in Other Tube Geometries / Experimental Correlation for Flow in Tubes / Thermal Entry Length for Turbulent Flow in a Circular Tube / Thermal Entry Length for Turbulent Flow between Parallel Planes / The Effects of Axial Variation of Surface Temperature and/or Heat Flux / Combined Hydrodynamic and Thermal Entry Length in a Circular Tube / The Influence of Surface Roughness / Problems / References

Chapter 14 The Influence of Temperature-Dependent Fluid Properties

Laminar Flow in Tubes: Liquids / Laminar Flow in Tubes: Gases / Turbulent Flow in Tubes: Liquids /

Turbulent Flow in Tubes: Gases / The Laminar External Boundary Layer: Gases / The Turbulent External Boundary Layer: Gases / Problems / References

Chapter 15 Convective Heat Transfer at High Velocities 288

The Stagnation Enthalpy Equation / The High-Velocity Thermal Boundary Layer for Fluid with $Pr = 1$ / The Laminar Constant-Property Boundary Layer for $Pr \neq 1$ / The Laminar Boundary Layer for a Gas with Variable Properties / The Use of Reference Properties for High-Velocity Laminar Boundary-Layer Calculations / The Turbulent Boundary Layer for a Gas with Variable Properties / Reference Properties for High-Velocity Turbulent Boundary Layer Calculations / Mach Number and large-Temperature-Difference Corrections for Variable Free-Stream Velocity and Variable Temperature Differences / Problems / References

Chapter 16 Free-Convection Boundary Layers 313

Boundary-Layer Equations for Free Convection / Similarity Solutions: Laminar Flow on a Constant-Temperature, Vertical, and Semi-Infinite Flat Plate / Similarity Solutions with Variable Surface Temperature / Similarity Solutions with Wall Suction or Blowing / Approximate Integral Solutions: Laminar Flow on a Constant-Temperature, Vertical, and Semi-Infinite Flat Plate / The Effect of Variable Properties / Free-Convection Flow Regimes / Turbulent Flow on a Vertical and Semi-Infinite Flat Plate / Heat-Transfer for Other Geometries / Mixed Free and Forced Convection / Problems / References

Chapter 17 Mass Transfer: Formulation of a Simplified Theory 332

Definitions / The Differential Equations of the Concentration Boundary Layer / Boundary Conditions at the Interface / Definition of the Mass-Transfer Conductance and Driving Force / Problems

Chapter 18 Mass Transfer: Some Solutions to the Conserved-Property Equation 352

The Laminar Constant-Property Boundary Layer,

Similarity Solutions / The Laminar Boundary Layer: Some Variable-Property Solutions / The Laminar Constant-Property Boundary Layer with Arbitrarily Varying Free-Stream Velocity / The Turbulent Constant-Property Boundary Layer with Constant Free-Stream Velocity / The Turbulent Boundary Layer: Some Variable-Property Solutions / Approximate Solutions to the Constant-Property Turbulent Boundary Layer for Arbitrarily Varying Free-Stream Velocity / Mass-Transfer Coefficients from Heat-Transfer Data / Problems / References

Chapter **19** Mass Transfer: Some Examples of Evaluation of the Driving Force 365

Thermodynamics of the Air-Water-Vapor System / Analysis of the Wet-Bulb Psychrometer / Modification of the Definition of B to Account for Thermal Radiation / Drying / Evaporative Cooling / Burning of a Volatile Fuel in Air / Simple Graphite Burning in Air / Graphite Ablation with More than One Reaction / The High-Temperature Boundary Layer with Dissociation / Transpiration Cooling by Gas Injection / Problems / References

Appendixes

A Property Values 387
B Dimensions and Conversion to SI 401
Some Tables of Functions Useful in Boundary-Laye Analysis 404
D Operations Implied By the ∇ Operator 406

Index