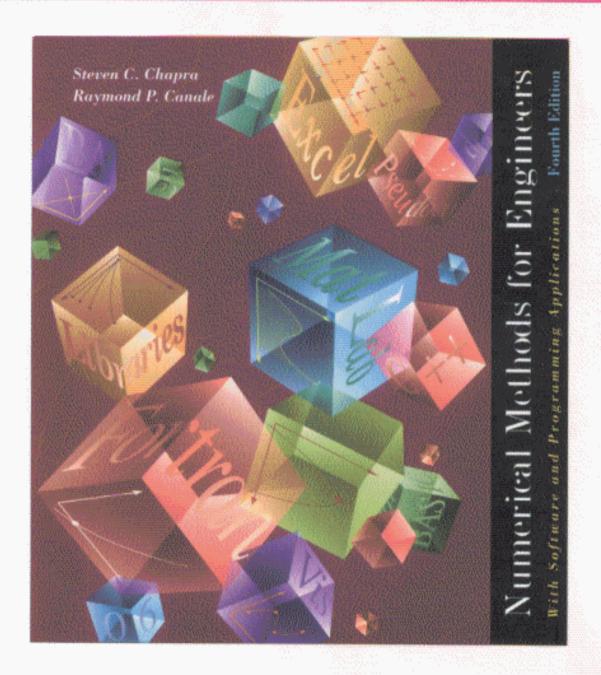
# INTERNATIONAL EDITION





#### PREFACE xvi

#### ABOUT THE AUTHORS xviii

# **PART ONE**

# MODELING, COMPUTERS, AND ERROR ANALYSIS 3

PT 1.1 Motivation 3

PT 1.2 Mathematical Background 5

PT 1.3 Orientation 8

#### **CHAPTER 1**

# Mathematical Modeling and Engineering Problem Solving 11

- 1.1 A Simple Mathematical Model 11
- 1.2 Conservation Laws and Engineering 18

Problems 21

#### **CHAPTER 2**

# Programming and Software 25

- 2.1 Packages and Programming 25
- 2.2 Structured Programming 26
- 2.3 Modular Programming 35
- 2.4 Excel 37
- 2.5 MATLAB 41
- 2.6 Other Languages and Libraries 45

Problems 46

#### **CHAPTER 3**

# Approximations and Round-Off Errors 50

- 3.1 Significant Figures 51
- 3.2 Accuracy and Precision 53
- 3.3 Error Definitions 54

		٠		
٧	I	ı	١	

3.4 Round-Off Errors 57 Problems 72

#### **CHAPTER 4**

# Truncation Errors and the Taylor Series 73

- 4.1 The Taylor Series 73
- 4.2 Error Propagation 89
- 4.3 Total Numerical Error 93
- 4.4 Blunders, Formulation Errors, and Data Uncertainty 95

Problems 97

#### **EPILOGUE: PART ONE 99**

PT 1.4 Trade-Offs 99

PT 1.5 Important Relationships and Formulas 102

PT 1.6 Advanced Methods and Additional References 102

## **PART TWO**

# ROOTS OF EQUATIONS 105

PT 2.1 Motivation 105

PT 2.2 Mathematical Background 107

PT 2.3 Orientation 108

#### **CHAPTER 5**

### **Bracketing Methods 112**

- 5.1 Graphical Methods 112
- 5.2 The Bisection Method 116
- 5.3 The False-Position Method 124
- 5.4 Incremental Searches and Determining Initial Guesses 130

Problems 131

# **CHAPTER 6**

#### Open Methods 133

- 6.1 Simple Fixed-Point Iteration 134
- 6.2 The Newton-Raphson Method 139
- 6.3 The Secant Method 145
- 6.4 Multiple Roots 150
- 6.5 Systems of Nonlinear Equations 153

Problems 157

#### **CHAPTER 7**

#### Roots of Polynomials 160

- 7.1 Polynomials in Engineering and Science 160
- 7.2 Computing with Polynomials 163
- 7.3 Conventional Methods 166
- 7.4 Müller's Method 167
- 7.5 Bairstow's Method 171
- 7.0 Ballolott of the line and the
- 7.6 Other Methods 176

7.7 Root Location with Libraries and Packages 176
Problems 185

#### **CHAPTER 8**

#### Engineering Applications: Roots of Equations 187

- 8.1 Ideal and Nonideal Gas Laws (Chemical/Bio Engineering) 187
- 8.2 Open-Channel Flow (Civil/Environmental Engineering) 190
- 8.3 Design of an Electric Circuit (Electrical Engineering) 194
- 8.4 Vibration Analysis (Mechanical/Aerospace Engineering) 196 Problems 203

#### **EPILOGUE: PART TWO 212**

- PT 2.4 Trade-Offs 212
- PT 2.5 Important Relationships and Formulas 213
- PT 2.6 Advanced Methods and Additional References 213

#### **PART THREE**

# LINEAR ALGEBRAIC EQUATIONS 217

- PT 3.1 Motivation 217
- PT 3.2 Mathematical Background 219
- PT 3.3 Orientation 227

#### **CHAPTER 9**

#### Gauss Elimination 231

- 9.1 Solving Small Numbers of Equations 231
- 9.2 Naïve Gauss Elimination 238
- 9.3 Pitfalls of Elimination Methods 244
- 9.4 Techniques for Improving Solutions 250
- 9.5 Complex Systems 257
- 9.6 Nonlinear Systems of Equations 257
- 9.7 Gauss-Jordan 259
- 9.8 Summary 261
- Problems 261

#### **CHAPTER 10**

# LU Decomposition and Matrix Inversion 264

- 10.1 LU Decomposition 264
- 10.2 The Matrix Inverse 273
- 10.3 Error Analysis and System Condition 277
- Problems 283

#### **CHAPTER 11**

#### Special Matrices and Gauss-Seidel 285

- 11.1 Special Matrices 285
- 11.2 Gauss-Seidel 289

11.3 Linear Algebraic Equations with Libraries and Packages 296
Problems 303

#### **CHAPTER 12**

# Engineering Applications: Linear Algebraic Equations 305

- 12.1 Steady-State Analysis of a System of Reactors (Chemical/Bio Engineering) 305
- 12.2 Analysis of a Statically Determinate Truss (Civil/Environmental Engineering)
- 12.3 Currents and Voltages in Resistor Circuits (Electrical Engineering) 312
- 12.4 Spring-Mass Systems (Mechanical/Aerospace Engineering) 314
  Problems 317

# **EPILOGUE: PART THREE 327**

- PT 3.4 Trade-Offs 327
- PT 3.5 Important Relationships and Formulas 328
- PT 3.6 Advanced Methods and Additional References 328

#### **PART FOUR**

# **OPTIMIZATION 331**

- PT 4.1 Motivation 331
- PT 4.2 Mathematical Background 336
- PT 4.3 Orientation 337

#### **CHAPTER 13**

# One-Dimensional Unconstrained Optimization 341

- 13.1 Golden-Section Search 342
- 13.2 Quadratic Interpolation 349
- 13.3 Newton's Method 351
- Problems 353

#### **CHAPTER 14**

# Multidimensional Unconstrained Optimization 355

- 14.1 Direct Methods 356
- 14.2 Gradient Methods 360
- Problems 373

#### **CHAPTER 15**

## **Constrained Optimization 375**

- 15.1 Linear Programming 375
- 15.2 Nonlinear Constrained Optimization 386
- 15.3 Optimization with Packages 387

Problems 398

#### **CHAPTER 16**

# **Engineering Applications: Optimization 400**

- 16.1 Least-Cost Design of a Tank (Chemical/Bio Engineering) 400
- 16.2 Least-Cost Treatment of Wastewater (Civil/Environmental Engineering) 405

16.3 Maximum Power Transfer for a Circuit (Electrical Engineering) 40916.4 Mountain Bike Design (Mechanical/Aerospace Engineering) 413Problems 415

#### **EPILOGUE: PART FOUR 422**

PT 4.4 Trade-Offs 422 PT 4.5 Additional References 423

# **PART FIVE**

#### 170011111

**CURVE FITTING** 

425

PT 5.1 Motivation 425
PT 5.2 Mathematical Background 427
PT 5.3 Orientation 436

## CHAPTER 17

# Least-Squares Regression 440

17.1 Linear Regression 44017.2 Polynomial Regression 456

17.3 Multiple Linear Regression 460

17.4 General Linear Least Squares 463

17.5 Nonlinear Regression 468
Problems 471

# CHAPTER 18 Interpolation 474

18.1 Newton's Divided-Difference Interpolating Polynomials 475

18.2 Lagrange Interpolating Polynomials 486

18.3 Coefficients of an Interpolating Polynomial 491

18.4 Inverse Interpolation 491

18.5 Additional Comments 492

18.6 Spline Interpolation 495 Problems 505

# **CHAPTER 19**

# Fourier Approximation 507

- 19.1 Curve Fitting with Sinusoidal Functions 508
- 19.2 Continuous Fourier Series 514
- 19.3 Frequency and Time Domains 517
- 19.4 Fourier Integral and Transform 521
- 19.5 Discrete Fourier Transform (DFT) 523
- 19.6 Fast Fourier Transform (FFT) 525
- 19.7 The Power Spectrum 532
- 19.8 Curve Fitting with Libraries and Packages 533

Problems 542

#### **CHAPTER 20**

#### Engineering Applications: Curve Fitting 544

- 20.1 Linear Regression and Population Models (Chemical/Bio Engineering) 544
- 20.2 Use of Splines to Estimate Heat Transfer (Civil/Environmental Engineering) 548
- 20.3 Fourier Analysis (Electrical Engineering) 550
- 20.4 Analysis of Experimental Data (Mechanical/Aerospace Engineering) 551

Problems 553

#### **EPILOGUE: PART FIVE 563**

- PT 5.4 Trade-Offs 563
- PT 5.5 Important Relationships and Formulas 564
- PT 5.6 Advanced Methods and Additional References 566

#### **PART SIX**

# NUMERICAL DIFFERENTIATION AND INTEGRATION 569

- PT 6.1 Motivation 569
- PT 6.2 Mathematical Background 578
- PT 6.3 Orientation 581

#### **CHAPTER 21**

# Newton-Cotes Integration Formulas 584

- 21.1 The Trapezoidal Rule 586
- 21.2 Simpson's Rules 596
- 21.3 Integration with Unequal Segments 605
- 21.4 Open Integration Formulas 608
- 21.5 Multiple Integrals 608

Problems 610

#### **CHAPTER 22**

# Integration of Equations 613

- 22.1 Newton-Cotes Algorithms for Equations 613
- 22.2 Romberg Integration 615
- 22.3 Gauss Quadrature 620
- 22.4 Improper Integrals 627

Problems 631

#### **CHAPTER 23**

#### **Numerical Differentiation 632**

- 23.1 High-Accuracy Differentiation Formulas 632
- 23.2 Richardson Extrapolation 635
- 23.3 Derivatives of Unequally Spaced Data 637
- 23.4 Derivatives and Integrals for Data with Errors 638
- 23.5 Numerical Integration/Differentiation with Libraries and Packages 639 Problems 643

#### **CHAPTER 24**

# Engineering Applications: Numerical Integration and Differentiation 646

xiii

- 24.1 Integration to Determine the Total Quantity of Heat (Chemical/Bio Engineering) 646
- 24.2 Effective Force on the Mast of a Racing Sailboat (Civil/Environmental Engineering) 648
- 24.3 Root-Mean-Square Current by Numerical Integration (Electrical Engineering) 650
- 24.4 Numerical Integration to Compute Work (Mechanical/Aerospace Engineering) 653Problems 657

#### **EPILOGUE: PART SIX 667**

PT 6.4 Trade-Offs 667

PT 6.5 Important Relationships and Formulas 668

PT 6.6 Advanced Methods and Additional References 668

## **PART SEVEN**

# ORDINARY DIFFERENTIAL EQUATIONS 671

PT 7.1 Motivation 671

PT 7.2 Mathematical Background 675

PT 7.3 Orientation 677

# CHAPTER 25

# Runge-Kutta Methods 681

- 25.1 Euler's Method 682
- 25.2 Improvements of Euler's Method 693
- 25.3 Runge-Kutta Methods 701
- 25.4 Systems of Equations 711
- 25.5 Adaptive Runge-Kutta Methods 716

Problems 724

# CHAPTER 26

# Stiffness and Multistep Methods 726

- 26.1 Stiffness 726
- 26.2 Multistep Methods 730

Problems 750

#### **CHAPTER 27**

# Boundary-Value and Eigenvalue Problems 752

- 27.1 General Methods for Boundary-Value Problems 753
- 27.2 Eigenvalue Problems 759
- 27.3 ODEs and Eigenvalues with Libraries and Packages 771

Problems 779

#### **CHAPTER 28**

#### Engineering Applications: Ordinary Differential Equations 781

- 28.1 Using ODEs to Analyze the Transient Response of a Reactor (Chemical/Bio Engineering) 781
- 28.2 Predator-Prey Models and Chaos (Civil/Environmental Engineering) 788
- 28.3 Simulating Transient Current for an Electric Circuit (Electrical Engineering) 792
- 28.4 The Swinging Pendulum (Mechanical/Aerospace Engineering) 797
  Problems 801

#### **EPILOGUE: PART SEVEN 808**

- PT 7.4 Trade-Offs 808
- PT 7.5 Important Relationships and Formulas 809
- PT 7.6 Advanced Methods and Additional References 809

#### **PART EIGHT**

# PARTIAL DIFFERENTIAL EQUATIONS 813

PT 8.1 Motivation 813

PT 8.2 Orientation 816

#### **CHAPTER 29**

#### Finite Difference: Elliptic Equations 820

- 29.1 The Laplace Equation 820
- 29.2 Solution Techniques 822
- 29.3 Boundary Conditions 828
- 29.4 The Control-Volume Approach 834
- 29.5 Software to Solve Elliptic Equations 837

Problems 838

#### **CHAPTER 30**

# Finite Difference: Parabolic Equations 840

- 30.1 The Heat Conduction Equation 840
- 30.2 Explicit Methods 841
- 30.3 A Simple Implicit Method 845
- 30.4 The Crank-Nicolson Method 849
- 30.5 Parabolic Equations in Two Spatial Dimensions 852

Problems 855

#### **CHAPTER 31**

#### Finite-Element Method 857

- 31.1 The General Approach 858
- 31.2 Finite-Element Application in One Dimension 862
- 31.3 Two-Dimensional Problems 871
- 31.4 Solving PDEs with Libraries and Packages 875

Problems 881

# CHAPTER 32 Engineering Applications: Partial Differential Equations 884

- 32.1 One-Dimensional Mass Balance of a Reactor (Chemical/Bio Engineering) 884
- 32.2 Deflections of a Plate (Civil/Environmental Engineering) 888
- 32.3 Two-Dimensional Electrostatic Field Problems (Electrical Engineering) 890
- 32.4 Finite-Element Solution of a Series of Springs (Mechanical/Aerospace Engineering) 893

Problems 797

#### **EPILOGUE: PART EIGHT 899**

PT 8.3 Trade-Offs 899

PT 8.4 Important Relationships and Formulas 899

PT 8.5 Advanced Methods and Additional References 900

#### APPENDIX A: THE FOURIER SERIES 901

APPENDIX B: GETTING STARTED WITH MATLAB 903

**BIBLIOGRAPHY 911** 

INDEX 915