CONTENTS

Preface xi

Chapter 1. Introduction 1
1.1 What Is Dynamics? 1
1.2 Organization of the Book 6
1.3 Key Ideas 8
1.4 Notes and Further Reading 9
1.5 Problems 10

Chapter 2. Newtonian Mechanics 11
2.1 Newton's Laws 11
2.2 A Deeper Look at Newton's Second Law 15
2.3 Building Models and the Free-Body Diagram 19
2.4 Constraints and Degrees of Freedom 21
2.5 A Discussion of Units 24
2.6 Tutorials 25
2.7 Key Ideas 37
2.8 Notes and Further Reading 38
2.9 Problems 38

PART ONE. PARTICLE DYNAMICS IN THE PLANE

Chapter 3. Planar Kinematics and Kinetics of a Particle 45
3.1 The Simple Pendulum 45
3.2 More on Vectors and Reference Frames 47
3.3 Velocity and Acceleration in the Inertial Frame 56
3.4 Inertial Velocity and Acceleration in a Rotating Frame 66
3.5 The Polar Frame and Fictional Forces 79
3.6 An Introduction to Relative Motion 83
3.7 How to Solve a Dynamics Problem 87
3.8 Derivations—Properties of the Vector Derivative 88
3.9 Tutorials 93
3.10 Key Ideas 100
3.11 Notes and Further Reading 101
3.12 Problems 102

Chapter 4. Linear and Angular Momentum of a Particle 113
4.1 Linear Momentum and Linear Impulse 113
4.2 Angular Momentum and Angular Impulse 117
4.3 Tutorials 131
4.4 Key Ideas 141
4.5 Notes and Further Reading 142
4.6 Problems 143

Chapter 5. Energy of a Particle 148
5.1 Work and Power 148
5.2 Total Work and Kinetic Energy 153
5.3 Work Due to an Impulse 158
5.4 Conservative Forces and Potential Energy 159
5.5 Total Energy 169
5.6 Derivations—Conservative Forces and Potential Energy 172
5.7 Tutorials 173
5.8 Key Ideas 179
5.9 Notes and Further Reading 180
5.10 Problems 181

PART TWO. PLANAR MOTION OF A MULTIPARTICLE SYSTEM

Chapter 6. Linear Momentum of a Multiparticle System 189
6.1 Linear Momentum of a System of Particles 189
6.2 Impacts and Collisions 205
6.3 Mass Flow 220
6.4 Tutorials 228
6.5 Key Ideas 235
6.6 Notes and Further Reading 237
6.7 Problems 237

Chapter 7. Angular Momentum and Energy of a Multiparticle System 245
7.1 Angular Momentum of a System of Particles 245
7.2 Angular Momentum Separation 252
7.3 Total Angular Momentum Relative to an Arbitrary Point 259
7.4 Work and Energy of a Multiparticle System 263
7.5 Tutorials 274
7.6 Key Ideas 285
7.7 Notes and Further Reading 287
7.8 Problems 288

PART THREE. RELATIVE MOTION AND RIGID-BODY DYNAMICS IN TWO DIMENSIONS

Chapter 8. Relative Motion in a Rotating Frame 295
8.1 Rotational Motion of a Planar Rigid Body 295
8.2 Relative Motion in a Rotating Frame 302
8.3 Planar Kinetics in a Rotating Frame 311
8.4 Tutorials 318
8.5 Key Ideas 328
8.6 Notes and Further Reading 329
8.7 Problems 330

Chapter 9. Dynamics of a Planar Rigid Body 337
9.1 A Rigid Body Is a Multiparticle System 337
9.2 Translation of the Center of Mass—Euler's First Law 340
9.3 Rotation about the Center of Mass— Euler's Second Law 343
9.4 Rotation about an Arbitrary Body Point 360

9.5 Work and Energy of a Rigid Body 368
9.6 A Collection of Rigid Bodies and Particles 376
9.7 Tutorials 385
9.8 Key Ideas 394
9.9 Notes and Further Reading 397
9.10 Problems 398

PART FOUR. DYNAMICS IN THREE DIMENSIONS

Chapter 10. Particle Kinematics and Kinetics in Three Dimensions 409
10.1 Two New Coordinate Systems 409
10.2 The Cylindrical and Spherical Reference Frames 413
10.3 Linear Momentum, Angular Momentum, and Energy 422
10.4 Relative Motion in Three Dimensions 426
10.5 Derivations—Euler's Theorem and the Angular Velocity 445
10.6 Tutorials 450
10.7 Key Ideas 458
10.8 Notes and Further Reading 459
10.9 Problems 460

Chapter 11. Multiparticle and Rigid-Body Dynamics in Three Dimensions 465
11.1 Euler's Laws in Three Dimensions 465
11.2 Three-Dimensional Rotational Equations of Motion of a Rigid Body 472
11.3 The Moment Transport Theorem and the Parallel Axis Theorem in Three Dimensions 495
11.4 Dynamics of Multibody Systems in Three Dimensions 502
11.5 Rotating the Moment of Inertia Tensor 504
11.6 Angular Impulse in Three Dimensions 509
11.7 Work and Energy of a Rigid Body in Three Dimensions 510
11.8 Tutorials 515
11.9 Key Ideas 523
11.10 Notes and Further Reading 526
11.11 Problems 527

PART FIVE. ADVANCED TOPICS

Chapter 12. Some Important Examples 537
12.1 An Introduction to Vibrations and Linear Systems 537
12.2 Linearization and the Linearized Dynamics of an Airplane 551
12.3 Impacts of Finite-Sized Particles 568
12.4 Key Ideas 578
12.5 Notes and Further Reading 579

Chapter 13. An Introduction to Analytical Mechanics 580
13.1 Generalized Coordinates 580
13.2 Degrees of Freedom and Constraints 583
13.3 Lagrange's Method 589

13.4 Kane's Method 605
13.5 Key Ideas 618
13.6 Notes and Further Reading 619

APPENDICES

Appendix A. A Brief Review of Calculus 623
A.1 Continuous Functions 623
A.2 Differentiation 624
A.3 Integration 626
A.4 Higher Derivatives and the Taylor Series 627
A.5 Multivariable Functions and the Gradient 629
A.6 The Directional Derivative 632
A.7 Differential Volumes and Multiple Integration 633

Appendix B. Vector Algebra and Useful Identities 635
B.1 The Vector 635
B.2 Vector Magnitude 637
B.3 Vector Components 637
B.4 Vector Multiplication 638

Appendix C. Differential Equations 645
C.1 What Is a Differential Equation? 645
C.2 Some Common ODEs and Their Solutions 647
C.3 First-Order Form 650
C.4 Numerical Integration of an Initial Value Problem 651
C.5 Using MATLAB to Solve ODEs 657

Appendix D. Moments of Inertia of Selected Bodies 660

Bibliography 663
Index 667