Contents

Preface xv List of Symbols xxiii

1

Introduction 1

- **1.1** What Is Mechanics? 2
- 1.2 Fundamental Concepts and Principles 2
- **1.3** Systems of Units 5
- 1.4 Conversion from One System of Units to Another 10
- 1.5 Method of Problem Solution 11
- **1.6** Numerical Accuracy 13

2 Statics of Particles 14

2.1 Introduction 16

Forces in a Plane 16

- 2.2 Force on a Particle. Resultant of Two Forces 16
- 2.3 Vectors 17
- 2.4 Addition of Vectors 18
- 2.5 Resultant of Several Concurrent Forces 20
- 2.6 Resolution of a Force into Components 21
- 2.7 Rectangular Components of a Force. Unit Vectors 27
- **2.8** Addition of Forces by Summing x and y Components 30
- 2.9 Equilibrium of a Particle 35
- 2.10 Newton's First Law of Motion 36
- 2.11 Problems Involving the Equilibrium of a Particle. Free-Body Diagrams 36

Forces in Space 45

- 2.12 Rectangular Components of a Force in Space 45
- **2.13** Force Defined by Its Magnitude and Two Points on Its Line of Action 48
- 2.14 Addition of Concurrent Forces in Space 49
- 2.15 Equilibrium of a Particle in Space 57

Review and Summary 64 Review Problems 67 Computer Problems 70

3 Rigid Bodies: Equivalent Systems of Forces 72

- 3.1 Introduction 74
- 3.2 External and Internal Forces 74
- 3.3 Principle of Transmissibility. Equivalent Forces 75
- 3.4 Vector Product of Two Vectors 77
- **3.5** Vector Products Expressed in Terms of Rectangular Components 79
- 3.6 Moment of a Force about a Point 81
- 3.7 Varignon's Theorem 83
- **3.8** Rectangular Components of the Moment of a Force 83
- 3.9 Scalar Product of Two Vectors 94
- 3.10 Mixed Triple Product of Three Vectors 96
- 3.11 Moment of a Force about a Given Axis 97
- 3.12 Moment of a Couple 108
- 3.13 Equivalent Couples 109
- 3.14 Addition of Couples 111
- 3.15 Couples Can Be Represented by Vectors 111
- **3.16** Resolution of a Given Force into a Force at *O* and a Couple 112
- **3.17** Reduction of a System of Forces to One Force and One Couple 123
- 3.18 Equivalent Systems of Forces 125
- **3.19** Equipollent Systems of Vectors 125
- **3.20** Further Reduction of a System of Forces 126
- ***3.21** Reduction of a System of Forces to a Wrench 128

Review and Summary 146 Review Problems 151 Computer Problems 154

4 Equilibrium of Rigid Bodies 156

- 4.1 Introduction 158
- 4.2 Free-Body Diagram 159 Equilibrium in Two Dimensions 160
- **4.3** Reactions at Supports and Connections for a Two-Dimensional Structure 160
- **4.4** Equilibrium of a Rigid Body in Two Dimensions 162
- **4.5** Statically Indeterminate Reactions. Partial Constraints 164
- **4.6** Equilibrium of a Two-Force Body 181
- 4.7 Equilibrium of a Three-Force Body 182

Equilibrium in Three Dimensions 189

- 4.8 Equilibrium of a Rigid Body in Three Dimensions 189
- **4.9** Reactions at Supports and Connections for a Three-Dimensional Structure 189

Review and Summary 210 Review Problems 213 Computer Problems 216

5 Distributed Forces: Centroids and Centers of Gravity 218

- 5.1 Introduction 220 Areas and Lines 220
- 5.2 Center of Gravity of a Two-Dimensional Body 220
- 5.3 Centroids of Areas and Lines 222
- 5.4 First Moments of Areas and Lines 223
- 5.5 Composite Plates and Wires 226
- 5.6 Determination of Centroids by Integration 236
- 5.7 Theorems of Pappus-Guldinus 238
- *5.8 Distributed Loads on Beams 248
- ***5.9** Forces on Submerged Surfaces 249

Volumes 258

- **5.10** Center of Gravity of a Three-Dimensional Body. Centroid of a Volume 258
- 5.11 Composite Bodies 261
- **5.12** Determination of Centroids of Volumes by Integration 261

Review and Summary 274 Review Problems 278 Computer Problems 281

6 Analysis of Structures 284

6.1 Introduction 286

Trusses 287

- 6.2 Definition of a Truss 287
- 6.3 Simple Trusses 289
- 6.4 Analysis of Trusses by the Method of Joints 290
- *6.5 Joints under Special Loading Conditions 292
- *6.6 Space Trusses 294
- 6.7 Analysis of Trusses by the Method of Sections 304
- *6.8 Trusses Made of Several Simple Trusses 305

Frames and Machines 316

- 6.9 Structures Containing Multiforce Members 316
- 6.10 Analysis of a Frame 316
- **6.11** Frames Which Cease to Be Rigid When Detached from Their Supports 317
- 6.12 Machines 331

Review and Summary 345 Review Problems 348 Computer Problems 350

Forces in Beams and Cables 352

- ***7.1** Introduction 354
- *7.2 Internal Forces in Members 354

Beams 362

- ***7.3** Various Types of Loading and Support 362
- ***7.4** Shear and Bending Moment in a Beam 363
- *7.5 Shear and Bending-Moment Diagrams 365
- ***7.6** Relations among Load, Shear, and Bending Moment 373

Cables 383

- *7.7 Cables with Concentrated Loads 383
- *7.8 Cables with Distributed Loads 384
- ***7.9** Parabolic Cable 385
- *7.10 Catenary 395

Review and Summary 403 Review Problems 406 Computer Problems 408

8 Friction 410

- 8.1 Introduction 412
- **8.2** The Laws of Dry Friction. Coefficients of Friction 412
- 8.3 Angles of Friction 415
- 8.4 Problems Involving Dry Friction 416
- 8.5 Wedges 429
- 8.6 Square-Threaded Screws 430
- *8.7 Journal Bearings. Axle Friction 439
- *8.8 Thrust Bearings. Disk Friction 441*8.9 Wheel Friction. Rolling
 - Resistance 442
- *8.10 Belt Friction 449

Review and Summary 460 Review Problems 463 Computer Problems 467

9 Distributed Forces: Moments of Inertia 470

- 9.1 Introduction 472 Moments of Inertia of Areas 473 9.2 Second Moment, or Moment of Inertia, of an Area 473 Determination of the Moment of Inertia of an 9.3 Area by Integration 474 9.4 Polar Moment of Inertia 475 9.5 Radius of Gyration of an Area 476 9.6 Parallel-Axis Theorem 483 9.7 Moments of Inertia of Composite Areas 484 *9.8 Product of Inertia 497 *9.9 Principal Axes and Principal Moments of Inertia 498 *9.10 Mohr's Circle for Moments and Products of Inertia 506 Moments of Inertia of a Mass 512 9.11 Moment of Inertia of a Mass 512 9.12 Parallel-Axis Theorem 514 9.13 Moments of Inertia of Thin Plates 515 9.14 Determination of the Moment of Inertia of a Three-Dimensional Body by Integration 516 9.15 Moments of Inertia of Composite Bodies 516 *9.16 Moment of Inertia of a Body with Respect to an Arbitrary Axis through O. Mass Products of Inertia 532 ***9.17** Ellipsoid of Inertia. Principal Axes of Inertia 533
- *9.18 Determination of the Principal Axes and Principal Moments of Inertia of a Body of Arbitrary Shape 535

Review and Summary 547 Review Problems 553 Computer Problems 555

10 Method of Virtual Work 556

- *10.1 Introduction 558
- *10.2 Work of a Force 558
- *10.3 Principle of Virtual Work 561
- *10.4 Applications of the Principle of Virtual Work 562
- *10.5 Real Machines. Mechanical Efficiency 564
- *10.6 Work of a Force during a Finite Displacement 578
- *10.7 Potential Energy 580
- *10.8 Potential Energy and Equilibrium 581
- *10.9 Stability of Equilibrium 582

Review and Summary 592 Review Problems 595 Computer Problems 598

Kinematics of Particles 600

11.1 Introduction to Dynamics 602 Rectilinear Motion of Particles 603 11.2 Position, Velocity, and Acceleration 603 11.3 Determination of the Motion of a Particle 607 11.4 Uniform Rectilinear Motion 616 11.5 Uniformly Accelerated Rectilinear Motion 617 11.6 Motion of Several Particles 618 *11.7 Graphical Solution of Rectilinear-Motion Problems 630 *11.8 Other Graphical Methods 631 Curvilinear Motion of Particles 641 Position Vector, Velocity, and Acceleration 641 11.9 **11.10** Derivatives of Vector Functions 643 11.11 Rectangular Components of Velocity and Acceleration 645 **11.12** Motion Relative to a Frame in Translation 646 **11.13** Tangential and Normal Components 665 11.14 Radial and Transverse Components 668 Review and Summary 682 Review Problems 686

Computer Problems 688

12 Kinetics of Particles: Newton's Second Law 690

- 12.1 Introduction 69212.2 Newton's Second Law of Motion 693
- **12.3** Linear Momentum of a Particle. Rate of Change of Linear Momentum 694
- **12.4** Systems of Units 695
- 12.5 Equations of Motion 697
- **12.6** Dynamic Equilibrium 699
- **12.7** Angular Momentum of a Particle. Rate of Change of Angular Momentum 721
- **12.8** Equations of Motion in Terms of Radial and Transverse Components 722
- **12.9** Motion under a Central Force. Conservation of Angular Momentum 723
- 12.10 Newton's Law of Gravitation 724
- *12.11 Trajectory of a Particle under a Central Force 734
- *12.12 Application to Space Mechanics 735
- *12.13 Kepler's Laws of Planetary Motion 738

Review and Summary 746 Review Problems 750 Computer Problems 753

13 Kinetics of Particles: Energy and Momentum Methods 754

- **13.1** Introduction 756
- **13.2** Work of a Force 756
- **13.3** Kinetic Energy of a Particle. Principle of Work and Energy 760
- 13.4 Applications of the Principle of Work and Energy 762
- 13.5 Power and Efficiency 763
- 13.6 Potential Energy 782
- ***13.7** Conservative Forces 784
- 13.8 Conservation of Energy 785
- **13.9** Motion under a Conservative Central Force. Application to Space Mechanics 787
- 13.10 Principle of Impulse and Momentum 806
- 13.11 Impulsive Motion 809
- 13.12 Impact 821
- 13.13 Direct Central Impact 821
- 13.14 Oblique Central Impact 824
- 13.15 Problems Involving Energy and Momentum 827

Review and Summary 843 Review Problems 849 Computer Problems 852

14 Systems of Particles 854

- 14.1 Introduction 856
- **14.2** Application of Newton's Laws to the Motion of a System of Particles. Effective Forces 856
- 14.3 Linear and Angular Momentum of a System of Particles 859
- 14.4 Motion of the Mass Center of a System of Particles 860
- 14.5 Angular Momentum of a System of Particles about Its Mass Center 862
- 14.6 Conservation of Momentum for a System of Particles 864
- 14.7 Kinetic Energy of a System of Particles 872
- **14.8** Work-Energy Principle. Conservation of Energy for a System of Particles 874
- **14.9** Principle of Impulse and Momentum for a System of Particles 874
- *14.10 Variable Systems of Particles 885
- *14.11 Steady Stream of Particles 885
- *14.12 Systems Gaining or Losing Mass 888

Review and Summary 905 Review Problems 909 Computer Problems 912

15 Kinematics of Rigid Bodies 914

- **15.1** Introduction 916
- 15.2 Translation 918
- 15.3 Rotation about a Fixed Axis 919
- **15.4** Equations Defining the Rotation of a Rigid Body about a Fixed Axis 922
- **15.5** General Plane Motion 932
- **15.6** Absolute and Relative Velocity in Plane Motion 934
- 15.7 Instantaneous Center of Rotation in Plane Motion 946
- **15.8** Absolute and Relative Acceleration in Plane Motion 957
- *15.9 Analysis of Plane Motion in Terms of a Parameter 959
- **15.10** Rate of Change of a Vector with Respect to a Rotating Frame 971
- **15.11** Plane Motion of a Particle Relative to a Rotating Frame. Coriolis Acceleration 973
- *15.12 Motion about a Fixed Point 984
- *15.13 General Motion 987
- ***15.14** Three-Dimensional Motion of a Particle Relative to a Rotating Frame. Coriolis Acceleration 998
- *15.15 Frame of Reference in General Motion 999

Review and Summary 1011 Review Problems 1018 Computer Problems 1021

16 Plane Motion of Rigid Bodies: Forces and Accelerations 1024

16.1 Introduction 1026 16.2 Equations of Motion for a Rigid Body 1027 16.3 Angular Momentum of a Rigid Body in Plane Motion 1028 16.4 Plane Motion of a Rigid Body. D'Alembert's Principle 1029 *16.5 A Remark on the Axioms of the Mechanics of Rigid Bodies 1030 Solution of Problems Involving the Motion of a 16.6 Rigid Body 1031 Systems of Rigid Bodies 1032 16.7 16.8 Constrained Plane Motion 1052 Review and Summary 1074 Review Problems 1076 Computer Problems 1079

17 Plane Motion of Rigid Bodies: Energy and Momentum Methods 1080

- 17.1 Introduction 1082
- **17.2** Principle of Work and Energy for a Rigid Body 1082
- 17.3 Work of Forces Acting on a Rigid Body 1083
- 17.4 Kinetic Energy of a Rigid Body in Plane Motion 1084
- 17.5 Systems of Rigid Bodies 1085
- 17.6 Conservation of Energy 1086
- **17.7** Power 1087
- **17.8** Principle of Impulse and Momentum for the Plane Motion of a Rigid Body 1103
- 17.9 Systems of Rigid Bodies 1106
- 17.10 Conservation of Angular Momentum 1106
- 17.11 Impulsive Motion 1119
- 17.12 Eccentric Impact 1119

Review and Summary 1135 Review Problems 1139 Computer Problems 1142

18 Kinetics of Rigid Bodies in Three Dimensions 1144

- *18.1 Introduction 1146
- ***18.2** Angular Momentum of a Rigid Body in Three Dimensions 1147
- ***18.3** Application of the Principle of Impulse and Momentum to the Three-Dimensional Motion of a Rigid Body 1151
- *18.4 Kinetic Energy of a Rigid Body in Three Dimensions 1152
- *18.5 Motion of a Rigid Body in Three Dimensions 1165
- *18.6 Euler's Equations of Motion. Extension of D'Alembert's Principle to the Motion of a Rigid Body in Three Dimensions 1166
- *18.7 Motion of a Rigid Body about a Fixed Point 1167
- *18.8 Rotation of a Rigid Body about a Fixed Axis 1168
- *18.9 Motion of a Gyroscope. Eulerian Angles 1184
- *18.10 Steady Precession of a Gyroscope 1186
- *18.11 Motion of an Axisymmetrical Body under No Force 1187

Review and Summary 1201 Review Problems 1206 Computer Problems 1209

19 Mechanical Vibrations 1212

19.1	Introduction 1214
	Vibrations without Damping 1214
19.2	Free Vibrations of Particles. Simple Harmonic Motion 1214
19.3	Simple Pendulum (Approximate Solution) 1218
*19.4	Simple Pendulum (Exact Solution) 1219
19.5	Free Vibrations of Rigid Bodies 1228
19.6	Application of the Principle of Conservation of Energy 1240
19.7	Forced Vibrations 1250
	Damped Vibrations 1260
*19.8	Damped Free Vibrations 1260
*19.9	Damped Forced Vibrations 1263
*19.10	Electrical Analogues 1264
Review and Summary 1277 Review Problems 1282 Computer Problems 1286	
Append	ix Fundamentals of Engineering Examination 1289

Appendix Fundamentals of Engineering Examination 1289 Photo Credits 1291 Index 1293 Answers to Problems 1305