# Instructor's and Solutions Manual

*to accompany*

# Vector Mechanics for Engineers, Dynamics

## Twelfth Edition


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## TO THE INSTRUCTOR

As indicated in its preface, *Vector Mechanics for Engineers: Dynamics* is designed for a first course in dynamics. New concepts have, therefore, been presented in simple terms and every step has been explained in detail. However, because of the large number of optional sections that have been included, this text can also be used to teach a course that will challenge the more advanced student.

The text has been divided into units, each corresponding to a well-defined topic and consisting of one or several theory sections, one or several Sample Problems, a section entitled *Solving Problems on Your Own*, and a large number of problems to be assigned. To assist instructors in making up schedules of assignments that will best fit their classes, the various topics covered in the text have been listed in Table I and a suggested number of periods to be spent on each topic has been indicated. Both a minimum and a maximum number of periods have been suggested, and the topics which form the standard basic course in dynamics have been separated from those that are optional. The total number of periods required to teach the basic material varies from 27 to 48, while covering the entire text would require from 40 to 67 periods. In most instances, of course, the instructor will want to include some, but not all, of the additional material presented in the text. If allowance is made for the time spent for review and exams, it is seen that this text is equally suitable for teaching the standard basic dynamics course in 40 to 45 periods and for teaching a more complete dynamics course to advanced students. In addition, it should be noted that *Statics* and *Dynamics* can be used together to teach a combined 4- or 5-credit-hour course covering all the essential topics in dynamics as well as those sections of statics that are prerequisites to the study of dynamics.

The problems have been grouped according to the portions of material they illustrate and have been arranged in order of increasing difficulty, with problems requiring special attention indicated by asterisks. We note that, in most cases, problems have been arranged in groups of six or more, all problems of the same group being closely related. This means that instructors will easily find additional problems to amplify a particular point they may have brought up in discussing a problem assigned for homework.

Educational research has shown that students can often choose appropriate equations and solve algorithmic problems without having a strong conceptual understanding of mechanics principles. To help assess and develop student conceptual understanding, we have included Concept Questions, which are multiple choice problems that require few, if any, calculations. Each possible incorrect answer typically represents a common misconception (e.g., students often think that a vehicle moving in a curved path at constant speed has zero acceleration). Students are encouraged to solve these problems using the principles and techniques discussed in the text and to use these principles to help them develop their intuition. Mastery and discussion of these Concept Questions will deepen students' conceptual understanding and help them to solve dynamics problems.

Drawing diagrams correctly is a critical step in solving kinetics problems in dynamics. A new type of problem has been added to the text to emphasize the importance of drawing these diagrams. In Chapters 12 and 16 the Free-Body Practice Problems require students to draw a free-body diagram (FBD) showing the applied forces and an equivalent diagram called a "kinetic diagram" (KD) showing $m\mathbf{a}$ (or its components) and $\bar{I}\alpha$. These diagrams provide students with a pictorial representation of Newton's second law and are critical in helping students to correctly solve kinetic problems. In Chapters 13 and 17 the Impulse-Momentum Practice problems require students to draw diagrams showing the momenta of the bodies before impact, the impulses exerted on the body during impact, and the final momenta of the bodies after the impact.

A group of problems designed to be solved with computational software, analyses of the problems, problem solutions and output for the most widely used computational programs can be found through the instructor resources available within Connect.

To assist in the preparation of homework assignments, Table II provides a brief description of all groups of problems and a classification of the problems in each group according to the units used. It should also be noted that the answers to all problems are given at the end of the text, except for those with a number in italic. Because of the large number of problems available in both systems of units, the instructor has the choice of assigning problems using SI units and problems using U.S. customary units in whatever proportion is found to be desirable. To illustrate this point, sample lesson schedules are shown in Tables III and IV, together with various alternative lists of assigned problems. Half of the problems in each of the six lists suggested in Table III are stated in SI units and half in U.S. customary units. On the other hand, 75% of the problems in the four lists suggested in Table IV are stated in SI units and 25% in U.S. customary units.

Because the approach used in this text differs in a number of respects from the approach used in other books, instructors will be well advised to read the preface to *Vector Mechanics for Engineers,* in which the authors have outlined their general philosophy. In addition, instructors will find in the following pages a description, chapter by chapter, of the more significant features of this text. It is hoped that this material will help instructors in organizing their courses to best fit the needs of their students.

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**DESCRIPTION OF THE MATERIAL CONTAINED IN**
***VECTOR MECHANICS FOR ENGINEERS: DYNAMICS*, Twelfth Edition**

## Chapter 11
## Kinematics of Particles

In this chapter, the motion of bodies is studied without regard to their size; all bodies are assumed to reduce to single particles. The analysis of the effect of the size of a body and the study of the relative motion of the various particles forming a given body are postponed until Chap. 15. In order to present the simpler topics first, Chap. 11 has been divided into two parts: rectilinear motion of particles, and curvilinear motion of particles.

In Sec. 11.1A, position, velocity, and acceleration are defined for a particle in rectilinear motion. They are defined as quantities which may be either positive or negative and students should be warned not to confuse the position coordinate and distance traveled, or velocity and speed. The significance of positive and negative acceleration should be stressed. Negative acceleration may indicate a loss in speed in the positive direction or a gain in speed in the negative direction.

As they begin the study of dynamics, many students are under the belief that the motion of a particle must be either uniform or uniformly accelerated. To destroy this misconception, the motion of a particle is first described under very general conditions, assuming a variable acceleration which may depend upon the time, the position, or the velocity of the particle (Sec. 11.1B). To facilitate the handling of the initial conditions, definite integrals, rather than indefinite integrals, are used in the integration of the equations of motion.

The special equations related to uniform and uniformly accelerated motion are derived in Secs. 11.2A and 11.2B. Before using these equations, students should be warned to check carefully that the motion under consideration is actually a uniform or a uniformly accelerated motion.

Two important concepts are introduced in Sec. 11.2C: (1) the concept of relative motion, which will be developed further in Secs. 11.4D, 15.2B and (2) the concept of dependent motions and degrees of freedom.

The first part of Chap. 11 ends with the presentation of several graphical methods of solution of rectilinear-motion problems (Sec. 11.3). This material is optional and may be omitted. Several problems in which the data are given in graphical form have been included.

The second part of the chapter begins with the introduction of the vectors defining the position, velocity and acceleration of a particle in curvilinear motion. The derivative of a vector function is defined and introduced at this point (Sec. 11.4B). The motion of a particle is first studied in terms of rectangular components (Sec. 11.4C); it is shown that in many cases (for example, projectiles) the study of curvilinear motion can be reduced to that of two independent rectilinear motions. The concept of fixed and moving frames of reference is introduced in Sec. 11.4D and is immediately used to treat the relative motion of particles.

The use of tangential and normal components, and of radial and transverse components is discussed in Secs. 11.5. Each system of components is first introduced in two dimensions and then extended to include three-dimensional space.

## Chapter 12
## Kinetics of Particles: Newton's Second Law

As indicated earlier, this chapter and the following two are concerned only with the kinetics of particles and systems of particles. They neglect the effect of the size of the bodies considered and ignore the rotation of the bodies about their mass center. The effect of size will be taken into account in Chaps. 16 through 18, which deal with the kinetics of rigid bodies.

Sec. 12.1 presents Newton's second law of motion and introduces the concept of a newtonian frame of reference. In Sec. 12.1B the concept of linear momentum of a particle is introduced, and Newton's second law is expressed in its alternative form, which states that the resultant of the forces acting on a particle is equal to the rate of change of the linear momentum of the particle. Section 12.1C reviews the two systems of units used in this text, the SI metric units and the U.S. customary units which were previously discussed in Sec. 1.3. This section also emphasizes the difference between an absolute and a gravitational system of units.

A number of problems with two degrees of freedom have been included (Problems 12.31 through 12.35), some of which require a careful analysis of the accelerations involved (see Sample Problem 12.5).

Section 12.1D applies Newton's second law to the study of the motion of a particle in terms of rectangular components, tangential and normal components, and radial and transverse components. The term *inertia vector* is used in preference to inertia force or effective force to avoid any possible confusion with actual forces.

In Sec. 12.2 the concept of angular momentum of a particle is introduced, and Newton's second law is used to show that the sum of the moments about a point *O* of the forces acting on a particle is equal to the rate of change of the angular momentum of the particle about *O*. Section 12.2B considers the particular case of the motion of a particle under a central force. The early introduction of the concept of angular momentum greatly facilitates the discussion of this motion. Section 12.2C presents Newton's law of gravitation and its application to the study of the motion of earth satellites.

Section 12.3 is optional. Section 12.3A derives the differential equation of the trajectory of a particle under a central force, while Sec. 12.3B discusses the trajectories of satellites and other space vehicles under the gravitational attraction of the earth. While the general equation of orbital motion is derived (Eq. 12.36), its application is restricted to launchings in which the velocity at burnout is parallel to the surface of the earth. (Oblique launchings are considered in Sec. 13.2D.) The periodic time is found directly from the fundamental definition of areal velocity rather than by formulas requiring a previous knowledge of the properties of conic sections.

Instructors may omit Section 12.3 and yet assign a number of interesting space mechanics problems to their students after they have reached Sec. 13.2D.

## Chapter 13
## Kinetics of Particles: Energy and Momentum Methods

After a brief introduction designed to give to students some motivation for the study of this chapter, the concept of work of a force is introduced in Sec. 13.1A. The term work is always used in connection with a well-defined force. Three examples considered are the work of a weight (i.e., the work of the force exerted by the earth on a given body), the work of the force exerted by a spring on a given body, and the work of a gravitational force. Confusing statements such as the work done on a body, or the work done on a spring are avoided.

The concept of kinetic energy is introduced in Sec. 13.1B and the principle of work and energy is derived by integration of Newton's equation of motion. In applying the principle of work and energy, students should be encouraged to draw separate sketches representing the initial and final positions of the body (Sec. 13.1C). Section 13.1D introduces the concepts of power and efficiency.

Section 13.2 is devoted to the concepts of conservative forces and potential energy and to the principle of conservation of energy. Potential energy should always be associated with a given conservative force acting on a body. By avoiding statements such as "the energy contained in a spring" a clearer presentation of the subject is obtained, which will not conflict with the more advanced concepts that students may encounter in later courses. In applying the principle of conservation of energy, students should again be encouraged to draw separate sketches representing the initial and final positions of the body considered.

In Sec. 13.2D, the principles of conservation of energy and conservation of angular momentum are applied jointly to the solution of problems involving conservative central forces. A large number of problems of this type, dealing with the motion of satellites and other space vehicles, are available for homework assignment. As noted earlier, these problems (except the last two, Probs. 13.117 and 13.118) can be solved even if Section 12.3 has been omitted.

The second part of Chap. 13 is devoted to the principle of impulse and momentum and to its application to the study of the motion of a particle. Section 13.3 introduces the concept of linear impulse and derives the principle of impulse and momentum from Newton's second law. The instructor should emphasize the fact that impulses and momenta are vector quantities. Students should be encouraged to draw three separate sketches when applying the principle of impulse and momentum and to show clearly the vectors representing the initial momentum, the impulses, and the final momentum. It is only after the concept of impulsive force has been presented that students will begin to appreciate the effectiveness of the method of impulse and momentum (Sec. 13.3B).

Direct central impact and oblique central impact are studied in Section 13.4. Note that the coefficient of restitution is defined as the ratio of the impulses during the period of restitution and the period of deformation. This more basic approach will make it possible in Chapter 17 to extend the results obtained here for central impact to the case of eccentric impact. Emphasis should be placed on the fact that, except for perfectly elastic impact, energy is not conserved. Note that the discussion of oblique central impact in Sec. 13.4B has been expanded to cover the case when one or both of the colliding bodies are constrained in their motions.

Section 13.4C shows how to select from the three fundamental methods studied in Chaps. 12 and 13 the one best suited for the solution of a given problem. It also shows how several methods can be combined to solve a given problem. Note that problems have been included (Probs. 13.177 through 13.189) which require the use of both the method of energy and the method of momentum in their solutions.

## Chapter 14
## Systems of Particles

Chapter 14 is devoted to the study of the motion of systems of particles. Sections 14.1A and 14.1B derive the fundamental equations (14.10) and (14.11) relating, respectively, the resultant and the moment resultant of the external forces to the rate of change of the linear and angular momentum of a system of particles. Sections 14.1C and 14.1D are devoted, respectively, to the motion of the mass center of a system and to the motion of the system about its mass center. Section 14.1E discusses the conditions under which the linear momentum and the angular momentum of a system of particles are conserved. Sections 14.2A and 14.2B deal with the application of the work-energy principle to a system of particles, and in Sec. 14.2C the application of the impulse-momentum principle is discussed.

A number of challenging problems have been provided to illustrate the application of the principles discussed in this chapter. The first group of problems (Probs. 14.1 through 14.30) deal chiefly with the conservation of the linear momentum of a system of particles and with the motion of the mass center of the system, while the second group of problems (Probs. 14.31 through 14.58) involve the combined use of the principles of conservation of energy, linear momentum, and angular momentum. However, the main purpose of these sections is to lay the proper foundation for the later study of the kinetics of rigid bodies (Chaps. 16 through 18). Depending upon the preparation and interest of the students, a greater or lesser emphasis may be placed on this part of the course. It is essential, however, that the significance of Eqs. (14.16) and (14.23) be pointed out to students, in view of the role played by these equations in the study of the motion of rigid bodies.

The instructor should note the distinction made in Sec. 14.1A between *equivalent* systems of forces (i.e., systems of forces which have the same effect) and *equipollent* systems of forces (i.e., systems of forces which have the same resultant and the same moment resultant). The equivalence of two systems of forces has been indicated in diagrams by *red* equals signs, and their equipollence by *blue* equals signs.

Section 14.3 is optional. It is devoted to the study of variable systems of particles, with applications to the determination of the forces exerted by deflected streams and the thrust of propellers, jet engines, and rockets. Since Newton's second law $\mathbf{F} = m\mathbf{a}$ was stated for a particle with a constant mass and does not apply, in general, to a system with a variable mass, the derivations given in Sec. 14.3A for a steady stream of particles and in Sec. 14.3B for a system gaining or losing mass are based on the consideration of an auxiliary system consisting of unchanging particles. This approach should give students a basic understanding of the subject and lead them to more advanced courses in mechanics of fluids.

**Chapter 15**
**Kinematics of Rigid Bodies**

With this chapter we start the study of the dynamics of rigid bodies. After an introduction in which the fundamental types of plane motion are defined, the relations defining the velocity and the acceleration of any given particle of a rigid body are established for two particular cases: translation (Sec. 15.1A) and rotation about a fixed axis (Secs. 15.1B and 15.1C).

In Sec. 15.2 it is shown that the most general plane motion can always be considered as the sum of a translation and a rotation. This property is established by considering the relative motion of two particles of the rigid body and is immediately applied in Sec. 15.2B to the determination of velocities.

Section 15.3 introduces the concept of the instantaneous center of rotation. The instructor should stress the fact that, while the instantaneous center method simplifies the solution of many problems involving velocities, it cannot be used to determine accelerations.

In Sec. 15.4 the concept of relative motion is used again, this time to determine accelerations in plane motion. Students should be warned against any unwarranted assumptions concerning the direction of unknown accelerations. Section 15.4B is optional. It presents an analytical method for the determination of velocities and accelerations based on the use of a parameter.

Section 15.5A discusses the rate of change of a vector with respect to a rotating frame, and Sec. 15.5B applies the results obtained to the determination of Coriolis acceleration in plane motion. It should be kept in mind, however, that Coriolis acceleration does not depend upon the existence of an actual slab or rod on which the particle moves. It can appear whenever *rotating* axes are used. There lies the fundamental difference between the approach of Sec. 15.5 and that of Secs. 11.4D and 15.4A where moving axes *of fixed direction* were used.

The remaining sections of Chap. 15 are devoted to the kinematics of rigid bodies in three dimensions and are optional. However, they should be included in a course covering the kinetics of rigid bodies in three dimensions (Chap. 18) and should be taught either at this point or immediately before Chap. 18.

In Sec. 15.6A the motion of a rigid body about a fixed point is presented. Students should note that while the finite rotations of a rigid body have magnitude and direction, the rotations are not vectors; on the other hand, both angular velocity and angular acceleration are vector quantities. In Sec. 15.6B, the general motion of a rigid body is analyzed. It should be emphasized that in this section the moving frame of reference is of fixed orientation and does not rotate.

Section 15.7 considers the motion of particles and rigid bodies with respect to rotating frames of reference and extend the concept of Coriolis acceleration to three-dimensional motion.

## Chapter 16
## Plane Motion of Rigid Bodies: Forces and Accelerations

This chapter is devoted to the plane motion of rigid bodies which consist of plane slabs or which are symmetrical with respect to the reference plane. Cases involving the plane motion of nonsymmetrical bodies and, more generally, the motion of rigid bodies in three dimensions are considered in Chap. 18. If the determination of mass moments of inertia has not been covered in the previous statics course, the instructor should include material from Appendix B at this point.

In Sec. 16.1 the fundamental relations derived in Chap. 14 for a system of particles are used to show that the external forces acting on a rigid body are equipollent to the vector $m\bar{\mathbf{a}}$ attached at the mass center $G$ of the body and the couple of moment $\dot{\mathbf{H}}_G$. This result, which is illustrated in Fig. 16.3, is valid in the most general case of motion of a rigid body (three-dimensional as well as plane motion).

It is shown in Sec. 16.1B that in the case of the plane motion of a slab or symmetrical body, the angular momentum $\mathbf{H}_G$ reduces to $\bar{I}\omega$ and its rate of change to $\bar{I}\alpha$. It is shown that the external forces acting on a rigid body are actually *equivalent* to the inertial terms represented by the vector $m\bar{\mathbf{a}}$ and the couple $\bar{I}\alpha$. As noted in Sec. 16.1D, this result is obtained independently of the principle of transmissibility and can be used to *derive* this principle from the other axioms of mechanics.

At this point students will have reached the climax of their study of rigid-body motion in two dimensions. Indeed, they can solve any problem by drawing two sketches—one showing the external forces, the other the vector $m\bar{\mathbf{a}}$ and the couple $\bar{I}\alpha$—and then by expressing that the two systems of vectors shown are equivalent.

The various types of plane motion problems have been grouped according to their kinematic characteristics. Translation, centroidal rotation, and plane motion consisting of a translation and an unrelated centroidal rotation are considered first, since they are the simplest ones to analyze. They are followed by plane motions with various kinematic constraints: non-centroidal rotation, rolling motion, and other types of plane motion. Problems involving systems of rigid bodies have been included at the end of this chapter (Probs. 16.126 through 16.141). The instructor should stress the fact that, in spite of the different kinematic characteristics of these various motions, the approach to the kinetics of the motion is consistently the same: all problems are solved by drawing two sketches—one showing the external forces, the other the vector $m\bar{\mathbf{a}}$ and the couple $\bar{I}\alpha$—and then expressing that the two systems of vectors are equivalent.

Since the approach used in this text differs from others in the emphasis placed on the direct application of Newton's second Law, rather than on specialized formulas, it might be appropriate at this point to summarize the advantages derived from this approach.

(1) A single method is emphasized, which applies to all cases of plane motion, regardless of their kinematic characteristics, and which can be used safely under any conditions. This is in contrast to using the equation $\Sigma M = I\alpha$ which is limited in its applications.

(2) By stressing the use of the free-body diagram and kinetic diagram, this method provides a better understanding of the kinetics of the motion. There will be little danger, for example, in the solution of a problem of non-centroidal rotation, that students will forget the effect of the acceleration of the mass center on the reaction at the fixed point, a mistake which occurs frequently when the specialized formula $\Sigma M_O = I_O \alpha$ is used.

(3) The method used divides the solution of a problem into two main parts, one in which the kinematic and kinetic characteristics of the problem are considered (separately if necessary), and the other in which the methods of statics are used. In this way the techniques of each separate field can be used most efficiently. For example, moment equations can be written to eliminate unwanted reactions, just as it was done in statics; this can be done independently of the kinetic characteristics of the problem.

(4) By resolving every plane motion (even a non-centroidal rotation) into a translation and a centroidal rotation, a unified approach is obtained, which will also be used in Chap. 17 with the method of work and energy and with the method of impulse and momentum, and which will be extended in Chap. 18 to the study of the three-dimensional motion of a rigid body. This approach is a basic one, which can be applied effectively throughout the study of mechanics in advanced courses as well as in elementary ones.

**Chapter 17**
**Plane Motion of Rigid Bodies: Energy and Momentum Methods**

The first portion of the chapter extends the method of work and energy, already used in Chap. 13, to the study of the plane motion of rigid bodies. The expressions for the work of a couple and for the kinetic energy of a rigid body are derived in Secs. 17.1B and 17.1C. Using the results obtained in Sec. 14.2A, the kinetic energy of a rigid body is separated into a translational part and a rotational part (about the mass center). The authors believe that, while it may lead to slightly longer solutions, this method is more fundamental and should be used in preference to special formulas. Indeed, it follows the basic idea of resolving every plane motion into a translation and a centroidal rotation.

It is shown in Sec. 17.1D that the method of work and energy is especially effective in the case of systems of rigid bodies connected by pins, inextensible cords, and meshed gears. In Sec. 17.1E the principle of conservation of energy is used to analyze the plane motion of rigid bodies.

In the second part of Chap. 17, the method of impulse and momentum is extended to the study of the motion of rigid bodies. The approach used is different from that of most elementary textbooks. Ready-to-use formulas are avoided; instead, students are taught to express the general principle of impulse and momentum by means of impulse-momentum diagrams and to write the equations most appropriate to the solution of the problem considered.

The results obtained in Sec. 14.2C for a system of particles are directly applicable to the system of particles forming a rigid body and can be used to analyze the plane motion of rigid bodies. It is shown in Sec. 17.2A that the momenta of the various particles forming a rigid body reduce to a vector $m\overline{\mathbf{v}}$ and a couple $\overline{I}\omega$ in the most general case of plane motion.

While the principle of conservation of angular momentum is discussed in Sec. 17.2C because of its physical and historical significance, it is not actually used in the solution of problems. To solve any problem, regardless of the type of motion, and whether it involves constant forces of finite magnitude applied for a finite time or impulsive forces applied for a very short time interval, students are told to draw three separate sketches showing, respectively, the initial momenta, the impulses of the external forces, and the final momenta. The momenta of a rigid body are represented in the most general case by a *momentum vector* $m\overline{\mathbf{v}}$ attached at the mass center and a *momentum couple* $\overline{I}\omega$. If students then consider the components of the vectors involved, they obtain relations between linear impulses and linear momenta. If they consider the moments of the same vectors, they obtain angular impulses and angular momenta. If, by equating moments about a point such as a pivot, they obtain an equation which does not involve any of the external forces, they will have automatically established conservation of angular momentum about that point.

The advantages derived from this approach can be summarized as follows:

(1) Students learn only one method of solution, a method based directly on a fundamental principle and which can be used safely under any conditions. This is in contrast with the equation $\sum M_0 \Delta t = I_0 \left(\omega_2 - \omega_1\right)$, which is limited in its applications.

(2) The method stresses the use of impulse and momentum diagrams and thus provides a better understanding of the kinetics of the motion. It is unlikely, for example, that students will forget an impulsive reaction at a fixed support.

(3) Students use the basic tools they learned in statics: reduction of a system of vectors to a vector and a couple and equations relating the components or the moments of these vectors.

(4) Again, the same unified approach is used: every plane motion is resolved into a translation and a centroidal rotation. In Chap. 18 this approach will be extended to the solution of problems involving the three-dimensional motion of rigid bodies.

Some teachers may fear that the inclusion of momentum vectors and momentum couples in the same diagrams may lead to confusion. This will not be the case, however, if students are instructed to write separate equations involving either components or moments, as they did in statics. The first equations will contain linear impulses and linear momenta expressed in N·s or lb·s, and the latter angular impulses and angular momenta expressed in N·m·s or lb·ft·s.

Section 17.3 is devoted to the eccentric impact of two rigid bodies, a topic seldom included in an elementary text. No special difficulty will be encountered, however, if separate sketches are used as indicated above.

## Chapter 18
## Kinetics of Rigid Bodies in Three Dimensions

In this chapter the restrictions imposed in preceding chapters (e.g., plane motion, symmetrical bodies) are lifted and students proceed to the analysis of more general (and more difficult) problems, such as the rotation of nonsymmetrical bodies about fixed axes and the motion of gyroscopes.

In Sec. 18.1, the general result obtained in Sec. 16.1 is recalled, namely, that the external forces acting on a rigid body are equipollent to the vector $m\bar{\mathbf{a}}$ attached at the mass center *G* of the body and the couple of moment $\dot{\mathbf{H}}_G$. It is also pointed out that the main feature of the impulse-momentum method, namely, the reduction of the momenta of the particles of a rigid body to a linear momentum vector $m\bar{\mathbf{v}}$ attached at *G* and an angular momentum, remains valid and that the work-energy principle and the principle of conservation of energy still apply in the case of the motion of a rigid body in three dimensions. The difficulties encountered in the study of the three dimensional motion of a rigid body are related to the determination of the angular momentum $\mathbf{H}_G$, of its rate of change $\dot{\mathbf{H}}_G$, and of the kinetic energy of the body.

The determination of the angular momentum $\mathbf{H}_G$ of a rigid body from its angular velocity $\boldsymbol{\omega}$ is discussed in Sec. 18.1A. Since this requires the use of mass products of inertia, as well as the use of mass moments of inertia, the instructor should cover the material from Appendix B (or from the second part of Chap. 9) if this material has not been included in the previous statics course.

Section 18.1B is devoted to the application of the impulse-momentum principle to the three-dimensional motion of a rigid body, and Sec. 18.1C to the determination of its kinetic energy.

In Secs. 18.2A and 18.2B, the rate of change of the angular momentum $\mathbf{H}_G$ is computed and the equations of motion for a rigid body in three dimensions are derived. Newton's second law is extended to the case of three-dimensional motion by showing that the external forces are actually *equivalent* to the inertial terms represented by the vector $m\bar{\mathbf{a}}$ and the couple $\dot{\mathbf{H}}_G$. Sections 18.2C and 18.2D are devoted to the particular cases of the motion of a rigid body about a fixed point and the rotation of a rigid body about a fixed axis, with applications to the balancing of rotating shafts.

While Euler's equations of motion have been derived, it should be noted that the more fundamental vector relations represented by Equations (18.22), (18.23), and (18.28) are used in the solution of problems.

The remaining portion of this chapter (Secs. 18.2D through 18.3C) is designed for advanced students and, in general, should be omitted for ordinary classes. In Secs. 18.3A and 18.3B the motion of a gyroscope is considered. At this point Eulerian angles are introduced. It should be carefully noted that the rotating system of axes *Oxyz* is attached to the inner gimbal; these axes are principal axes of inertia and they follow the precession and nutation of the gyroscope; they do not, however, spin with the gyroscope. The special case of steady precession is considered in Sec. 18.3B. Several problems dealing with the steady precession of a top and other axisymmetrical bodies have been included and, in one of them (Prob. 18.110), it is shown that the formula usually given in introductory texts is only approximate.

The motion of an axisymmetrical body under no force (Sec. 18.3C) introduces students to one of the most interesting aspects of classical dynamics—an aspect which has gained widespread attention in recent years due to the interest in space vehicles and artificial satellites. In this connection, it should be pointed out that Poinsot's theory of the motion of a nonsymmetrical body under no force may be covered by assigning Probs. 18.143 through 18.145. An additional problem (Prob. 18.146) relates to the stability of the rotation of a nonsymmetrical body about a principal axis.

**Chapter 19**
**Mechanical Vibrations**

This chapter provides an introduction to the study of mechanical vibrations. While only one-degree-of-freedom systems are included, all the basic principles are presented. The various topics covered are as follows:

*(a) Free, undamped vibrations of a particle* (Sec. 19.1A). The differential equation characterizing simple harmonic motion is derived and all basic terms, such as period, natural frequency, and amplitude, are defined. Both the analytical and the geometrical methods of solution are described. It is shown in Sec. 19.1B that the motion of a simple pendulum can be approximated by a simple harmonic motion. Section 19.1C, which is optional, shows how an exact solution can be obtained for the period of oscillations of a simple pendulum.

*(b) Free, undamped vibrations of a rigid body.* The principle of equivalence of the systems of applied forces and inertial terms is first used to determine the natural frequency and the period of oscillations of a rigid body (Sec. 19.2). Note that the same positive sense is assumed for the angular acceleration and displacement. The principle of conservation of energy is then used to solve the same type of problems (Sec. 19.3).

(*c*) *Forced, undamped vibrations of a particle* (Sec. 19.4). This section introduces students to the concepts of forced frequency, transient and steady-state vibrations, and resonance. While all students will be able to understand this section, those with a knowledge of elementary differential equations will derive a greater benefit from it since it provides a direct application of the solution of linear nonhomogeneous equations with constant coefficients.

*(d) Free, damped vibrations of a particle* (Sec. 19.5A), and

*(e) Forced, damped vibrations of a particle* (Sec. 19.5B). These two sections take into account the effect of friction and thus provide a more rigorous analysis of the vibrations of a particle. They are not recommended, however, to students who do not possess a basic knowledge of elementary differential equations.

In Sec. 19.5C the electrical analogue for a vibrating mechanical system is discussed; this section is optional and should not be assigned unless Secs. 19.5A and 19.5B have been covered.

TABLE I. LIST OF TOPICS COVERED IN *VECTOR MECHANICS FOR ENGINEERS: DYNAMICS*

| | | **Suggested Number of Periods** | |
|---|---|---|---|
| **Sections** | **Topics** | **Basic Course** | **Additional Topics** |
| 11. KINEMATICS OF PARTICLES | | | |
| 11.1 | Rectilinear Motion | 1 | |
| 11.2 | Special Cases and Relative Motion | 1 | |
| *11.3 | Graphical Methods | | 1 |
| 11.4 | Curvilinear Motion (Rectangular Components) | 1-2 | |
| 11.5 | Tangential and Normal Components | 0.5-1 | |
| 11.5B | Radial and Transverse Components | 0.5-1 | |
| 12. KINETICS OF PARTICLES: NEWTON'S SECOND LAW | | | |
| 12.1 | Newton's Second Law and Linear Momentum | | 1-2 |
| 12.2 | Angular Momentum and Orbital Mechanics | 1-2 | |
| *12.3 | Applications of Central-Force Motion | | 1-2 |
| 13. KINETICS OF PARTICLES: ENERGY AND MOMENTUM METHODS | | | |
| 13.1 | Work and Energy | 1-2 | |
| 13.2 | Conservation of Energy; Central Forces | 1-2 | |
| 13.3 | Impulse and Momentum; Impulsive Motion | 1-2 | |
| 13.4 | Impact; Mixed Problems | 1-2 | |
| 14. SYSTEMS OF PARTICLES | | | |
| 14.1 | Motion of Systems of Particles | 0.5-1 | |
| 14.2 | Energy and Momentum Methods for Systems of Particles | 0.5-1 | |
| *14.3 | Variable Systems of Particles | | 1-2 |
| 15. KINEMATICS OF RIGID BODIES | | | |
| 15.1 | Translation; Rotation About a Fixed Axis | 1-1.5 | |
| 15.2 | Velocities in Plane Motion | 1-1.5 | |
| 15.3 | Instantaneous Center | 1 | |
| 15.4 | Accelerations in Plane Motion | 1-2 | 0.5 |
| 15.5 | Motion With Respect to a Rotating Frame | 1-2 | |
| *15.6 | Motion of a Rigid Body in Space | | 1-2 |
| *15.7 | Motion Relative to a Moving Reference Frame | | 1-2 |
| 16. PLANE MOTION OF RIGID BODIES: FORCES AND ACCELERATIONS | | | |
| 16.1 | Kinetics of a Rigid Body in Plane Motion | 2-3 | |
| 16.2 | Constrained Plane Motion | 2-4 | |
| 17. PLANE MOTION OF RIGID BODIES: ENERGY AND MOMENTUM METHODS | | | |
| 17.1 | Energy Methods for a Rigid Body | 1-2 | |
| 17.2 | Momentum Methods for a Rigid Body | 1-2 | |
| 17.3 | Eccentric Impact | 1-2 | |

| | | | |
|---|---|---|---|
| 18. KINETICS OF RIGID BODIES IN THREE DIMENSIONS | | | |
| *18.1 | Energy and Momentum in Three Dimensions | | 2 |
| *18.2 | Motion of a Rigid Body in Three Dimensions | | 1-2 |
| *18.3 | Motion of a Gyroscope | | 2 |
| 19. MECHANICAL VIBRATIONS | | | |
| 19.1 | Vibrations of Particles without Damping | | 1-2 |
| *19.1C | Exact Solution of a Simple Pendulum | | 0.5 |
| 19.2 | Free Vibrations of Rigid Bodies | 1-2 | |
| 19.3 | Energy Methods | | 1-1.5 |
| 19.4 | Forced Vibrations | 1-1.5 | |
| *19.5 | Damped Vibrations | | 1-2 |
| *19.5C | Electrical Analogues | | 1 |
| | Total Number of Periods | 27-48 | 13-19 |

TABLE II: CLASSIFICATION AND DESCRIPTION OF PROBLEMS

| **Problem Number*** | | |
|---|---|---|
| **SI Units** | **U.S. Units** | **Problem Description** |
| | | CHAPTER 11: KINEMATICS OF PARTICLES |
| | | RECTILINEAR MOTION OF PARTICLES |
| | | Analyze the motion of a particle given |
| 11.3,4 | 11.1,2 | position = *f(t)* |
| 11.5,7 | | |
| | 11.*6,8* | also find total distance traveled |
| 11.11,12 | 11.9,10 | acceleration = *f(t)* |
| 11.*13,14* | | |
| 11.15,18 | 11.16,17 | acceleration = *f(x)* |
| 11.*19,20* | | |
| 11.21,24 | 11.22,23 | acceleration = *f(v)* |
| 11.25,26 | | |
| 11.27 | 11.28 | velocity = *f(x)* |
| | 11.*29,30* | acceleration $\propto 1/r^2$ |
| 11.31 | 11.32 | Simple harmonic motion |
| | | Uniformly accelerated motion |
| 11.33,34 | 11.35,36 | motion of one particle |
| 11.*37,38* | | |
| 11.39,40 | 11.41,42 | motion of two particles |
| 11.44,*45* | 11.43,*46* | |
| | | Relative motion of particles |
| 11.47,49 | 11.48,50 | systems with one degree of freedom |
| 11.51,52 | 11.*53,54* | |
| 11.57,58 | 11.55,56 | systems with two degrees of freedom |
| 11.*59,60* | | |
| | | Graphical methods |
| | 11.*61,62* | analyze motion using a given motion curve |
| 11.63,64 | | |
| 11.66 | 11.65 | motion of one particle |
| 11.69,70 | 11.*67,68* | |

| | | |
|---|---|---|
| 11.71,75 | 11.72,73 | motion of two particles |
| 11.*76* | 11.74 | |
| 11.78 | 11.*77*,79 | problems involving rate of change of acceleration |
| | 80 | |
| 11.*81,82* | 11.83 | problems solved by numerical integration |
| | 11.84 | problem solved using a $v$-$x$ curve |
| 11.*87,88* | 11.85,*86* | problems solved using the moment-area method |

CURVILINEAR MOTION OF PARTICLES

| | | |
|---|---|---|
| | | Analyze the motion of a particle given |
| 11.89,90 | 11.91,92 | $x$ and $y$ as functions of $t$ |
| 11.*93* | 11.*94* | the position vector: two dimensions |
| 11.95 | *11.96 | the position vector: three dimensions |

* Problems which do not involve any specific system of units have been indicated by underlining their numbers.
Answers are not given to problems with the numbers set in italic type.

TABLE II: CLASSIFICATION AND DESCRIPTION OF PROBLEMS (CONTINUED)

| Problem Number* | | |
|---|---|---|
| **SI Units** | **U.S. Units** | **Problem Description** |
| | | Projectiles |
| 11.99,99 | 11.97,100 | with horizontal initial velocity |
| 11.102,103 | 11.*101,104* | with initial velocity of a given magnitude and direction |
| 11.106,108 | 11.105,107 | for a given direction, find magnitude of initial velocity |
| 11.*109,110* | | |
| 11.111,114 | 11.112,113 | for a given magnitude, find direction of initial velocity |
| 11.*115*,**116* | | (Solution of a quadratic equation is required.) |
| | | Relative motion of particles with |
| 11.118,120 | 11.117,119 | constant velocities |
| 11.*121,122* | | |
| | 11.123, 124 | given velocities and accelerations |
| 11.125,126 | | given relative acceleration |
| | 11.127,128 | constant accelerations |
| 11.129,131 | 11.*130,132* | two given observations of relative motion |
| | | Normal and tangential components |
| 11. 133,134,135 | 11. 136 | zero tangential acceleration |
| 11.138,139 | 11.137,141 | constant tangential acceleration |
| 11.*140,142* | | |
| 11.144,145 | 11.143,146 | find radii of curvature of trajectory |
| 11.147,149 | 11.*148*,*150* | |
| *11.151 | *11.152 | find radius of curvature of a curve in three dimensions |
| 11.153,154 | 11.156,157 | problems involving a satellite in a circular orbit |
| 11.158,159 | 11.*157,160* | |
| | | Radial and transverse components |
| 11.163,164 | 11.161,162 | given $r$ and $\theta$ as functions of time |
| 11.165,166 | | |
| 11.*167*,*168* | 11.169,*170 | find relations among $v$, $a$, $\dot{\theta}$, and $\ddot{\theta}$ |
| 11.171 | 11.172 | find approximate velocity from two observations of $r$ and $\theta$ |
| | | for motion along a spiral |
| 11.*174* | 11.*173* | find velocity |
| 11.175 | 11.176 | find acceleration |
| 11.*177* | 11.*179* | motion of a particle in three dimensions: cylindrical coordinates |
| | 11.178 | motion of a particle along a hyperbola or a circle |
| *11.180 | *11.181 | find direction of the binormal |

| | | |
|---|---|---|
| 11.182,183 | 11.*186*,187 | Review problems |
| 11.*184*,185 | 11.189,190 | |
| 11.188,*192* | 11.191,*193* | |

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## CHAPTER 12: KINETICS OF PARTICLES

### NEWTON'S SECOND LAW

| | | |
|---|---|---|
| 12.3,4 | 12.1,2 | Definition of mass and weight |
| | | Rectilinear motion |
| 12.7,8 | 12.5,6 | single particles |
| 12.*9*,*10* | | |

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* Problems which do not involve any specific system of units have been indicated by underlining their numbers.
Answers are not given to problems with the numbers set in italic type.

TABLE II: CLASSIFICATION AND DESCRIPTION OF PROBLEMS (CONTINUED)

| **Problem Number*** | | |
|---|---|---|
| **SI Units** | **U.S. Units** | **Problem Description** |
| 12.11,12 | 12.*13,14* | several connected bodies |
| 12. 17,18 | 12. 15,16 | |
| 12.19 | | |
| 12.20,*21* | | two bodies with impending relative motion |
| 12.*22*,23 | | |
| 12. 24,25 | 12.*26,27* | problems with variable acceleration |
| 12.28,30 | 12.29,31 | systems with two degrees of freedom |
| 12.*32,33* | | |
| 12.34,35 | | |
| | | Curvilinear motion: normal and tangential components |
| 12.36,37 | | circular paths contained in a horizontal plane |
| 12.38,39 | | |
| 12.40,*41* | *12.42,*43 | motion defined by two criteria |
| 12.46,47 | 12.44,45 | circular paths contained in a vertical plane |
| 12.48,49 | | |
| 12.50,51 | | |
| | 12.52 | cars traveling on banked curves |
| | 12,53,*54* | |
| 12.55,56 | | impending relative motion of a particle with respect to a moving support |
| 12.57,58 | 12.*60* | |
| 12,*59* | 12.62,63 | |
| 12.64 | 12.65 | cathode-ray tubes |
| | | Curvilinear motion: radial and transverse components |
| 12.68,69 | 12.66,67 | find acceleration of and/or forces acting on a particle for a given motion |
| 12.71,72 | 12.*70,73* | |
| 12.*74,75* | 12.*76,77* | motion under a central force: theoretical problems |
| 12.79,81 | 12.78,80 | motion defined by Newton's Law of Gravitation |
| 12.82,85 | 12.*83,84* | |
| | | Conservation of angular momentum |
| 12.86,87 | 12.88,89 | orbital motion of spacecraft |
| 12.90,*93* | 12.91,*92* | mechanical devices |
| | | Trajectory of a particle under a central force |
| 12.96,97 | 12.94,95 | determination of the central force for a given trajectory |
| 12.98,100 | 12.*99* | analysis of spacecraft orbits |
| 12.101 | | |

| | | |
|---|---|---|
| 12.102,104 | 12.103,105 | analysis of more advanced orbital problems |
| | 12.*106*,107 | |
| 12.108 | 12.109 | determination of the time in orbit |
| 12.*110*,*111* | | |
| 12.112,113 | | |
| 12.115,*116* | 12.114,*117* | determination of the point of impact of a descending spacecraft |
| 12.119,120 | 12.118,121 | derivation of classical formulas |
| 12.*123*,126 | 12.*122*,124 | Review problems |
| 12.127,128 | 12.125,130 | |
| 12.*129*,*131* | 12.131,132 | |

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* Problems which do not involve any specific system of units have been indicated by underlining their numbers.
Answers are not given to problems with the numbers set in italic type.

TABLE II: CLASSIFICATION AND DESCRIPTION OF PROBLEMS (CONTINUED)

| **Problem Number*** | | |
|---|---|---|
| **SI Units** | **U.S. Units** | **Problem Description** |
| | | CHAPTER 13: KINETICS OF PARTICLES<br>ENERGY AND MOMENTUM METHODS |
| 13.1,*4* | 13.2,*3* | Determine kinetic energy |
| 13.7,8 | 13.5,6 | Method of work and energy applied to problems involving |
| 13.9,*10* | | a single body |
| 13.11,12 | 13.*13,14* | |
| 13.15,16 | 13.17,18 | two connected bodies |
| 13.21,22 | 13.19,20 | |
| 13.23 | | |
| 13.24 | 13.25 | a body which drops out of the system |
| 13.26,27 | 13.28.29 | work of springs |
| 13.*30,31* | | |
| 13.32,*35* | 13.33,34 | work of non-linear forces |
| 13.37,38 | 13.36 | work of a gravitational force |
| 13.39,40 | 13.41,*42* | use of $F = ma$ |
| 13.44 | 13.*43*,45 | |
| 13.46,47 | | Introductory problems involving power and efficiency |
| 13.48,51 | 13.*49,50* | Power in uniform and uniformly accelerated motion |
| 13.52,*53* | 13.54 | |
| | | Method of conservation of energy applied to problems involving |
| 13.55,*56* | 13.58,59 | springs in a horizontal plane |
| 13.57 | | |
| 13.*60,61* | | |
| 13.64,65 | 13.62,*63* | springs and the effect of gravity |
| 13.68,69 | 13.66,*67* | |
| 13.70,71 | 13.72,*73* | use of $F = ma$ |
| 13.76,77 | 13.74,*75* | |
| | *13.78 | |
| 13.*79,80 | 13.*81,*82 | Theory problems on conservative forces |
| 13.**83*,**84* | | |
| 13.85,86 | 13.87,88 | Space mechanics problems involving gravitational potential energy |
| 13.89,90 | 13.*91,92* | |
| 13.93,94 | 13.95,96 | Conservation of energy and conservation of angular momentum |
| 13.*98,99* | 13.97 | |
| | | Applications to space mechanics |
| 13.100,103 | 13.101,102 | velocity perpendicular to the radius vector |
| 13.*104,105* | | |

| | | |
|---|---|---|
| 13.106,107 | 13.110,*111 | velocity oblique to the radius vector |
| 13.108,109 | 13.*112*,*113* | |
| 13.*114,115 | 13.116,*117 | derivations and theoretical problems |
| 13.*118 | | |
| | | Method of impulse and momentum applied to problems involving |
| 13.119,120 | 13.121 | a single body |
| 13.*122*,123 | 13.124,125 | |
| 13.126,*128* | 13.*127* | |

* Problems which do not involve any specific system of units have been indicated by underlining their numbers.
Answers are not given to problems with the numbers set in italic type.

| **Problem Number*** | | |
|---|---|---|
| **SI Units** | **U.S. Units** | **Problem Description** |
| 13.131,132 | 13.129,130 | two bodies |
| 13.*133* | | |
| 13.*135* | 13.134 | a force defined by a graph |
| 13.136 | 13.*137*,138 | |
| 13.141,142 | 13.139,140 | impulsive motion of a single body |
| 13.*143,144* | | |
| 13.146,147 | 13.145,148 | impulsive motion of two bodies |
| | 13.149 | |
| 13.151,152 | 13.150 | impulsive motion with different supports |
| | 13.*153,154* | |
| 13.155,156 | 13.157,158 | Direct central impact |
| 13.*159,160* | 13,161 | |
| 13.*162*,163 | | |
| 13.166,167 | 13.164,165 | Oblique central impact |
| 13.168 | | |
| 13.169 | 13.*170,171* | Impact against fixed surfaces |
| 13.172,173 | | |
| 13.175,177 | 13.174,176 | Problems involving energy and momentum in direct impact |
| 13.179,180 | 13.*178,181* | |
| 13.182,183 | | |
| 13.185,186 | 13.184,188 | Problems involving energy and momentum in oblique impact |
| 13.*187,189* | | |
| *13.193*,195 | 13.190,191 | Review problems |
| 13.197,198 | 13.192,194 | |
| 13.*199*,200 | 13.*196*,*201* | |

## CHAPTER 14: SYSTEMS OF PARTICLES

| | | |
|---|---|---|
| 14.1,2 | 14.3,4 | Conservation of linear momentum (one dimension) |
| 14.7,8 | 14.*5,6* | |
| 14.9,10 | 14.11,12 | Conservation of angular momentum |
| 14.*13,14* | | |
| 14.15,16 | 14.19,20 | Motion of mass center |
| 14.*17,18* | | |

| | | |
|---|---|---|
| 14.24,25 | 14.21,22 | Conservation of linear momentum (2 or 3 dimensions) |
| 14.26 | 14.*23* | |
| 14.*27*,28 | 14.29,30 | Derivations and proofs |
| 14.31,34 | 14.32,33 | Conservation of linear momentum and computation of change in kinetic energy |
| 14.*34,36* | | |

* Problems which do not involve any specific system of units have been indicated by underlining their numbers.
Answers are not given to problems with the numbers set in italic type.

| **Problem Number*** | | |
|---|---|---|
| **SI Units** | **U.S. Units** | **Problem Description** |
| 14.37,38 | 14.39,40 | Conservation of linear momentum and conservation of energy |
| 14.43,44 | 14.*41*,*42* | |
| 14.45,48 | 14.46,47 | Conservation of linear and angular momentum |
| | 14.*49,50* | |
| 14.51,52 | 14.55,56 | Conservation of linear momentum, angular momentum and energy |
| 14.*53*,*54* | | |
| 14.57,68 | 14.59,60 | Thrust caused by a diverted flow |
| 14.61,62 | | |
| 14.64,66 | 14.*63*,*65* | Reactions at supports of vanes or conveyor belts |
| 14.67,68 | | |
| 14.69,71 | 14.70,72 | Thrust developed by a jet engine, a propeller, or a fan |
| 14.*73*,*75* | 14.74 | |
| 14.76 | | |
| 14.77,78 | | Power and efficiency |
| 14.79 | 14.80 | |
| 14. *81*,*83* | 14.82,**84* | Theory problems from fluid mechanics |
| 14.**85* | | |
| 14.86,87 | 14.*88* | Motion of chains |
| | 14.90,91 | Motion of a toy car |
| 14.91,94 | 14.*92,93* | Thrust of rockets |
| 14.95,96 | 14.*97,98* | |
| 14.101 | 14.99,100 | |
| | 14.102 | |
| | 14.103,104 | Efficiency formulas for jet engine and rocket |
| 14.106,107 | 14.*105*,108 | Review problems |
| 14.*109*,110 | 14.112,*113* | |
| 14.*111*,115 | 14.114,116 | |

## CHAPTER 15: KINEMATICS OF RIGID BODIES

| | | |
|---|---|---|
| | | Rotation about a fixed axis |
| 15.1,2 | 15.3,4 | solutions using equations |
| 15.5,6 | 15.7,8 | |
| 15.9 | | |

| | | |
|---|---|---|
| 15.10,11 | 15.12,13 | rotation about a skew axis |
| 15.*14*,*15* | | |
| 15.17 | 15.16 | motion of the earth |
| 15.18,19 | | motion in two dimensions |
| 15.*20,21* | 15.22,23 | |
| | 15.24 | |
| 15.26,27 | 15.25 | rolling contact with no slipping |
| 15.29,30 | 15.28,31 | linear and angular motion |
| 15.*34,35* | 15.32,33 | disks brought into contact |
| *15.36 | *15.37 | special problems |

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* Problems which do not involve any specific system of units have been indicated by underlining their numbers.
Answers are not given to problems with the numbers set in italic type.

TABLE II: CLASSIFICATION AND DESCRIPTION OF PROBLEMS (CONTINUED)

| Problem Number* | | |
|---|---|---|
| **SI Units** | **U.S. Units** | **Problem Description** |
| | | General plane motion: velocities |
| 15.40,41 | 15.38,39 | motion of s single rigid body |
| 15.*42,43* | | |
| 15.44,45 | | application of vector algebra to motion of a plate |
| 15.*46*,47 | | |
| 15.49,50 | 15.48,*52* | planetary gear systems |
| 15.51 | 15.53,*54* | |
| | | motion of rod connected to |
| 15.55,56 | 15.57,58 | a crank and a sliding block |
| 15.61,62 | 15. *59,60* | |
| 15.63,64 | | two cranks |
| 15.65 | 15.*66,67* | |
| 15.68,69 | 15.70,72 | motion involving a rolling wheel |
| 15.71 | | |
| | | Instantaneous center of rotation |
| 15.76,77 | 15.*73*,74 | problems involving parallel velocities |
| 15.78,79 | 15.75,*81* | |
| 15.80 | | |
| 15.*84,85* | 15.82,83 | single rod: angle between controlling velocities $= 90°$ |
| 15.86,87 | | |
| 15.88,90 | 15.89 | single rod angle between controlling velocities $\neq 90°$ |
| 15.*91*,*92* | | |
| 15.*93* | 15.94 | |
| 15.96,97 | 15.95,98 | problems involving two instantaneous centers |
| 15.100 | 15.99 | space and body centrodes |
| 15.102,103 | 15.*101*,*104* | previous problems solved using instantaneous center |
| | | General plane motion: accelerations |
| 15.105,106 | | find relations among accelerations ( $\omega = 0$) |
| 15.107,108 | 15.109,110 | |
| 15.111 | 15.112,113 | rolling motion |
| 15.115,*116* | 15.114 | |
| 15.*117*,*119* | 15.118 | |
| | | motion of a body controlled by |
| 15.120,121 | 15.*123*,124 | one crank and a sliding block |
| 15.122 | 15.125,*126* | |
| 15.127,128 | 15.129,130 | two cranks |

| | | |
|---|---|---|
| 15.132,134 | 15.131,133 | |
| 15.136 | 15.135 | |
| 15.137 | | special problems |
| *15.138,*139 | *15.140,*141 | analysis of plane motion in terms of a parameter |
| *15._142_,*143 | *15._144_,147 | |
| *15._145_,*_146_ | *15._148_,*149 | |

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* Problems which do not involve any specific system of units have been indicated by underlining their numbers.
Answers are not given to problems with the numbers set in italic type.

TABLE II: CLASSIFICATION AND DESCRIPTION OF PROBLEMS (CONTINUED)

| Problem Number* SI Units | U.S. Units | Problem Description |
|---|---|---|
| | | Plane motion of a particle relative to a rotating frame |
| 15.150,151 | 15.152,155 | velocity of a particle with respect to a rotating frame |
| 15.153,154 | 15.*156,157* | |
| | | Coriolis acceleration |
| 15.160,162 | 15.*158,159* | acceleration of a particle moving at constant speed with respect to |
| 15.163,164 | 15.161 | frame rotating with constant velocity |
| 15.165,166 | | |
| 15.167,168 | | |
| 15.169 | 15.170,171 | |
| 15.*172,173* | | |
| 15.174,175 | | acceleration of a particle with respect to a frame rotating with an |
| 15.176,177 | | angular acceleration |
| 15.178 | 15.*179,180* | |
| *15.183 | 15.**181*,**182* | |
| | | Motion about a fixed point. General Motion |
| 15.184,185 | | relation between linear and angular velocity for a rigid body with |
| 15.186 | 15.187 | a fixed point |
| 15.190,*191* | 15.188,189 | angular acceleration of a body rotating simultaneously about two axes |
| 15.*192*,193 | 15.*194*,195 | |
| 15.197,198 | 15.196 | velocity and/or acceleration of a body rotating about a fixed point |
| 15.199,200 | 15.*201*,*202* | |
| 15.205 | 15.203,204 | rod attached to moving collars: find velocities of collars (angular velocity |
| 15.*208*,*209* | 15.206,207 | is indeterminate) |
| | 15.210,211 | universal joints |
| 15.213 | 15.112 | rod with clevis attached at one end |
| 15.*214* | 15.*215*,216 | rod attached to moving collars: find acceleration of collars (angular velocities |
| 15.218,219 | 15.117 | and angular accelerations are indeterminate) |
| | | Three dimensional motion of a particle relative to a rotating frame. Coriolis Acceleration |
| 15.222,223 | 15.220,221 | $\dot{\Omega} = 0$ and $\dot{u} = 0$ |
| 15.224 | 15.*225*,*226* | |
| 15.227,228 | | |
| 15.*229* | 15.230 | $\Omega$ and u not constant |
| 15.231,233 | 15.232 | previous problems to be solved using rotating frames |
| 15.234,235 | 15.236 | axis of $\Omega$ in plane of mechanism |

| | | |
|---|---|---|
| 15.*237*,*238* | 14,239 | |
| 15.244,245 | 15.240,241 | frame of reference in general motion |
| 15.*246*,*247* | 15.242,243 | |

| | | |
|---|---|---|
| 15.248,*251* | 15.249,*250* | Review problems |
| 15.252,*254* | 15.253,*257* | |
| 15.255,256 | 15.258,259 | |

* Problems which do not involve any specific system of units have been indicated by underlining their numbers.
Answers are not given to problems with the numbers set in italic type.

| **Problem Number*** | | |
|---|---|---|
| **SI Units** | **U.S. Units** | **Problem Description** |
| | | CHAPTER 16: PLANE MOTION OF RIGID BODIES |
| | | FORCES AND ACCELERATIONS |
| | | Rectilinear translation |
| 16.4,5 | 16.1,2 | find reactions or accelerations |
| 16.6 | 16.3 | |
| 16.9,10 | 16.*7*,*8* | determine whether body tips or slides |
| 16.11,*12* | | |
| | | Curvilinear translation |
| 16.*13*,14 | | bodies with zero velocity ( $a_n = 0$ ) |
| 16.15,*16* | | |
| 16.*17* | | |
| | 16.18 | bodies with velocities ( $a_n \neq 0$ ) |
| | 16.19,20 | |
| 16.**22* | 16.**21* | draw shear and bending-moment diagrams for accelerated rod |
| | | Centroidal rotation |
| 16.23 | 16.24 | proofs that effective forces reduce to $m\bar{\mathbf{a}}$ and $\bar{I}\alpha$ |
| 16.25,29 | 16.26,27 | single body |
| 16.30,31 | 16.28 | |
| 16.*32*,35 | 16.33,34 | connected pulleys and blocks |
| 16.*36* | 16.*37*,*38* | |
| 16.41,42 | 16.39,40 | friction disks |
| 16.43,44 | 16.45 | |
| | | General plane motion |
| 16.46 | 16.47 | proofs concerning system of effective forces |
| 16.50,51 | 16.48,49 | find accelerations for given loading |
| 16.*53*,*54* | 16.52 | |
| 16.55,56 | 16.57,60 | vertical motion controlled by applied forces and gravity |
| 16.58,59 | 16.*61*,*62* | |
| 16.63 | 16.64,65 | bars suspended from springs and suddenly released |
| 16.66,67 | 16.*68* | |
| 16.69,70 | 16.71,72 | spheres, disks, or hoops rotating and sliding on horizontal surface |
| 16.*73*,*74* | | |

| | | |
|---|---|---|
| | | Non-centroidal rotation |
| 16.75 | | derivation involving center of percussion |
| 16.76,77 | 16.78,79 | find acceleration and reactions for a suspended body |
| | | find reactions for a body rotating with |

| | | |
|---|---|---|
| 16.80,83 | 16.*81*,*82* | constant angular velocity |
| 16.84 | 16.85,86 | angular acceleration and velocity |
| 16.87,*90* | 16.88,*89* | two connected bodies |
| 16.*91* | | |
| | Rolling motion | |
| 16.92 | 16.93 | derivations involving use of $\Sigma M_C = I_C \alpha$ |
| 16.*96*,*97* | 16.94,95 | single body rolling on an incline under gravity |

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* Problems which do not involve any specific system of units have been indicated by underlining their numbers.
Answers are not given to problems with the numbers set in italic type.

TABLE II: CLASSIFICATION AND DESCRIPTION OF PROBLEMS (CONTINUED)

| **Problem Number*** | | |
|---|---|---|
| **SI Units** | **U.S. Units** | **Problem Description** |
| 16.98,99 | 16.102,103 | single body rolling, or rotating and sliding |
| 16.*100*,*101* | 16.104,105 | |
| 16.108,109 | 16.*106*.107 | connected bodies |
| | 16.*110* | |
| 16.113,114 | 16.111,112 | unbalanced bodies |
| | 16.115,116 | |
| | | General plane motion |
| | | single rigid body, find accelerations and reactions |
| 16.119,120 | 16.117,118 | problems in which the velocity is zero |
| 16.121,*122* | | |
| 16.*123* | | |
| 16.124,127 | 16.125,126 | problems in which the velocity is not zero |
| 16.128,129 | | |
| 16.*130*,131 | | |
| | 16.*132*,*133* | problems involving an integration |
| | | connected rigid bodies |
| 16.135,136 | 16.134 | systems with one degree of freedom |
| 16.137,138 | 16.139,140 | |
| 16.*142* | 16.*141* | needs rotating axis |
| 16.*<u>143</u>,*145 | 16.*<u>144</u> | systems with two degrees of freedom |
| 16.*146, | 16.*147,*148 | |
| 16.*149,*150 | | |
| 16.*<u>150</u> | 16.*151,*152 | draw shear and bending-moment diagrams for accelerated rod |
| 16.*155*,<u>156</u> | 16.153,154 | Review problems |
| 16.*159*,<u>160</u> | 16.<u>157,158</u> | |
| 16.163,164 | 16.*161*,*164* | |

<u>CHAPTER 17: PLANE MOTION OF RIGID BODIES</u>

ENERGY AND MOMENTUM METHODS

ENERGY METHODS

| | | |
|---|---|---|
| | | Centroidal rotation |
| 17.1,4 | 17.2,3 | single body with applied couple |
| 17.6 | 17.5 | |
| 17.11,12 | 17.7,<u>*8*</u> | connected bodies |
| 17.13,*14* | 17.*9*,10 | |
| 17.*15* | | |

| | Noncentroidal rotation | |
|---|---|---|
| 17.17 | 17.16,18 | |
| 17.21,22 | 17.19,20 | |
| 17.*23,24* | | |

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* Problems which do not involve any specific system of units have been indicated by underlining their numbers.
Answers are not given to problems with the numbers set in italic type.

TABLE II: CLASSIFICATION AND DESCRIPTION OF PROBLEMS (CONTINUED)

| Problem Number* | | |
|---|---|---|
| **SI Units** | **U.S. Units** | **Problem Description** |
| | | Rolling motion |
| 17.25,26 | 17.27 | single body |
| 17.*28*,29 | 17.30 | |
| 17.31 | | |
| 17.34,*35* | 17.32,33 | connected bodies |
| | | General plane motion |
| 17.36,37 | 17.39,40 | single body |
| 17.38 | 17.*41* | |
| 17.42,43 | | connected bodies |
| 17.44,45 | | |
| 17.46,47 | | |
| 17.49,50 | 17.48,51 | Power |
| | | MOMENTUM METHODS |
| | | Centroidal rotation |
| 17.52,54 | 17.53,55 | single body |
| 17.*56*,*57* | 17.58,59 | |
| 17.*60*,*61* | 17.63,64 | connected bodies |
| 17.62 | | |
| 17.65,66 | 17.67,68 | Derivations involving noncentroidal rotation (center of percussion) |
| | | Rolling motion |
| 17.70,71 | 17.69 | single body |
| 17.74,75 | 17.72,*73* | connected bodies |
| | 17.*76* | |
| 17.77 | 17.78 | sliding and rotating sphere |
| | | Conservation of angular momentum |
| 17.79 | 17.80 | problems involving changes in the configuration of a rotating assembly |
| 17.82,83 | 17.81 | problems involving relative motion between components of a rotating assembly |
| 17.86,87 | 17.*84*,*85* | |
| 17.88,89 | 17.90,91 | problems involving conservation of energy |
| 17.*92*,*93* | 17.95 | |
| 17.94 | | |
| | | Eccentric impact |
| 17.96 | 17.97,98 | projectile becomes embedded in a body suspended from a fixed point |
| 17.101,102 | 17.99,100 | |
| 17.102,103 | 17. 104,105 | single body, rotation about a fixed point |
| 17.106,107 | 17.108,109 | |

| | | |
|---|---|---|
| 17.*110*,*111* | 17.112 | |
| 17.*113* | | |
| 17.*114*,115 | 17.118,119 | problems involving method of work and energy |
| 17.116,117 | 17.120 | |
| 17.121,122 | 17.123,124 | two bodies, general plane motion |
| 17.*126* | 17.*125* | |
| 17.127,128 | *17.130* | |
| 17.*129* | | |
| 17.131,*134 | 17.132,133 | special problems |

* Problems which do not involve any specific system of units have been indicated by underlining their numbers.
Answers are not given to problems with the numbers set in italic type.

TABLE II: CLASSIFICATION AND DESCRIPTION OF PROBLEMS (CONTINUED)

| **Problem Number*** | | |
|---|---|---|
| **SI Units** | **U.S. Units** | **Problem Description** |
| 17.*138*,<u>139</u> | 17.135,136 | Review problems |
| 17.140,*141* | 17.137,<u>142</u> | |
| 17.143,145 | 17.*<u>144</u>*,*146* | |

<u>CHAPTER 18: KINETICS OF RIGID BODIES IN THREE DIMENSIONS</u>

| | | |
|---|---|---|
| 18.1,5 | 18.2,3 | Computation of angular momentum (no product of inertia) |
| 18.7,8 | 18.*4*,*6* | |
| 18.10,12 | 18.9,11 | Use of equation $\mathbf{H}_O = \overline{\mathbf{r}} \times m\overline{\mathbf{v}} + \mathbf{H}_G$ |
| 18.*13*,*14* | | |
| 18.15,16 | 18.17,18 | Computation of angular momentum (using products of inertia) |
| 18.*19*,*20* | | |
| 18.21,22 | 18.*23*,*24* | Impulse and momentum in three dimensions |
| 18.27,28 | 18.25,26 | |
| 18.*<u>29</u>*,*<u>30</u>* | 18.<u>31</u>,<u>32</u> | impact problems |
| 18.35,36 | 18.33,34 | |
| 18.37 | 18.38 | |
| 18.<u>39</u>,43 | 18.40,41 | Computation of kinetic energy |
| 18.<u>44</u>,<u>45</u> | 18.42,*<u>46</u>* | |
| 18.47,49 | 18.*48* | |
| 18.50 | | |
| 18.*<u>51</u>*,*<u>52</u>* | 18.53,54 | |
| 18.<u>55</u>,59 | 18.56,57 | Computation of derivative of angular momentum |
| 18.<u>60</u> | 18.58,*61* | |
| 18.*63*,<u>64</u> | 18.*62* | |
| | | Dynamic reactions on rotating shaft |
| 18.65,68 | 18.66,67 | for $\omega$ = constant |
| 18.*69*,*70* | | |
| 18.<u>71</u>,74 | 18.72,73 | for $\omega = 0$ and $\alpha \neq 0$ |
| 18.*77*,*78* | 18.75,76 | |
| 18.79,81 | 18.*80*,*83* | Simple problems on gyroscopic effect |
| 18.82,84 | | |
| 18.86,87 | 18.85,88 | Relative equilibrium under rotation about a fixed axis |
| 18.90,91 | 18.*89*,*92* | |

| | | |
|---|---|---|
| | | Dynamic reactions for combined rotations |
| 18.95,96 | 18.93,94 | with constant rates |
| 18.99,100 | 18.*97*,*98* | |
| 18.103,104 | 18.101,102 | with variable rates |
| 18.105,*106 | | |
| 18.109,*110* | 18.107,*108* | Steady precession. Simple problems |
| | 18.111,112 | |

* Problems which do not involve any specific system of units have been indicated by underlining their numbers.
Answers are not given to problems with the numbers set in italic type.

TABLE II: CLASSIFICATION AND DESCRIPTION OF PROBLEMS (CONTINUED)

| **Problem Number*** | | |
|---|---|---|
| **SI Units** | **U.S. Units** | **Problem Description** |
| 18.115,116 | 18,113.114 | Steady precession. More advanced problems |
| 18.*118* | 18.117 | |
| 18.119,120 | 18.121,122 | Precession under no force (theory) |
| 18.*123*,124 | 18.*125*,128 | Precession under no force (applications) |
| 18.126,127 | 18.*129*,130 | |
| | | Conservation of energy and angular momentum |
| 18.131,*134* | 18.132,133 | for bodies with precession and nutation |
| 18.135,136 | | |
| 18.*139,*140 | 18.*137,*138 | for bodies with precession, nutation, and spin |
| | 18.**141*,**142* | |
| 18.*143,144 | 18.*145,*146 | Poinsot analysis |
| 18.148,151 | 18.*147*,*149* | Review problems |
| 18.*152*,153 | 18.150,154 | |
| 18.155,157 | 18.156,*158* | |

## CHAPTER 19: MECHANICAL VIBRATIONS

### VIBRATIONS WITHOUT DAMPING

| SI Units | U.S. Units | Problem Description |
|---|---|---|
| | | Free vibrations of a particle |
| 19.1,4 | 19.2,3 | problems involving amplitude, frequency, maximum velocity and acceleration |
| 19.5,7 | 19.6,*9* | |
| 19.8 | 19.*10* | |
| 19.14,*15* | 19.11,12 | problems involving velocity and acceleration at a given instant |
| 19.*16* | 19.13 | |
| 19.17,20 | 19.18,18 | springs in parallel or in series |
| 19.*21*,*22* | | |
| 19.24,26 | 19.23,25 | change mass or stiffness of the system |
| 19.28,30 | 19.*27*,29 | special problems |
| 19.31 | 19.*32* | |
| 19.*34,*36 | 19.*33,*35 | simple pendulum with large amplitude |
| | | Free vibrations of rigid bodies |
| 19.37,39 | 19.38,41 | systems with elastic restoring forces |
| 19.*40*,*43* | 19.42 | |

| | | |
|---|---|---|
| 19.44,45 | 19.*46*,*47* | systems with restoring forces due to gravity |
| 19.48,49 | 19.50,51 | |
| 19.52,53 | 19.54 | derivations for motion of compound pendulum |
| 19.55,56 | 19.57,*58* | systems with elastic and gravity restoring forces |
| 19.60,62 | 19.59,*61* | determine velocity and acceleration |
| 19.63,64 | 19.67,68 | torsional vibrations |
| 19.*65*.*66* | | |

* Problems which do not involve any specific system of units have been indicated by underlining their numbers.
Answers are not given to problems with the numbers set in italic type.

TABLE II: CLASSIFICATION AND DESCRIPTION OF PROBLEMS (CONTINUED)

| **Problem Number*** | | |
|---|---|---|
| **SI Units** | **U.S. Units** | **Problem Description** |
| | | Conservation of energy used to analyze the motion of |
| 19.69,72 | 19.70,71 | particles |
| 19.75,76 | 19.*73*,*74* | single rigid body; pendulum |
| 19.77,80 | 19.78,79 | single rigid body; elastic restoring forces |
| 19.*81*,*82* | | |
| 19.83,*84* | 19.85,86 | connected rigid bodies |
| 19.87,*88* | | |
| 19.89,92 | 19.90,91 | special problems |
| 19.95,96 | 19.93,94 | |
| 19.*98 | 19.*97 | |
| | | Forced vibrations |
| 19.99,100 | 19.101,102 | problems involving periodic applied force |
| 19.*103*,*104* | | |
| 19.106,107 | 19.105,*108* | problems involving periodic support motion |
| 19.109,112 | 19.110,*111* | |
| 19.113,114 | 19.115,116 | problems involving rotating machinery |
| 19.117,119 | 19.*118*,*120* | |
| 19.121,122 | 19.123,125 | special problems |
| 19.*124*,*126* | | |
| | | DAMPED VIBRATIONS |
| | | Damped free vibrations |
| 19.127 | 19.128 | proofs concerning damped free vibration |
| 19. 129,130 | 19.131 | proofs involving the logarithmic decrement |
| 19.133 | 19.132 | problems that use logarithmic decrement |
| 19.136 | 19.134,135 | maximum deflection of damped free vibration |
| 19.137 | 19.138 | damped free vibration of a rigid body |
| 19.141,142 | 19.139,140 | Damped forced vibrations |
| 19.144 | 19.143,145 | problems involving rotating machinery |
| | 19.146 | |
| 19.147,148 | 19.149, | forced transmission with damping |
| | 19.*150 | energy dissipation |
| 19.151*,152* | | write the differential equation |
| 19.153,154 | 19.155,156 | Electrical analogues |
| 19.157,158 | | |

| | | |
|---|---|---|
| 19.159,162 | 19. 160,161 | Review problems |
| 19.*166*,*167* | 19. *163*,*164* | |
| 19.168,170 | 19. 165,169 | |

* Problems which do not involve any specific system of units have been indicated by underlining their numbers.
Answers are not given to problems with the numbers set in italic type.

TABLE III: SAMPLE ASSIGNMENT SCHEDULE FOR A COURSE IN DYNAMICS

This schedule includes all of the material of *VECTOR MECHANICS FOR ENGINEERS: DYNAMICS* with the exception of Sections 11.7, 11.8, 12.11–12.13, 18.9–18.11 and 19.8–19.10.

50% OF THE PROBLEMS IN EACH OF THE FOLLOWING LISTS USE SI UNITS AND 50% U.S. CUSTOMARY UNITS

| | | | ANSWERS TO ALL OF THESE PROBLEMS ARE GIVEN IN THE BACK OF THE BOOK | | | | NO ANSWERS ARE GIVEN IN THE BOOK FOR ANY OF THESE PROBLEMS | |
|---|---|---|---|---|---|---|---|---|
| Period | Sections | Topics | List 1 | List 2 | List 3 | List 4 | List 5 | List 6 |
| 1 | 11.1 | Introduction | | | | | | |
| 2 | 11.1 | Rectilinear Motion | 11.3,10,15,23 | 11.4,9,18,22 | 11.1,12,16,24 | 11.2,11,17,21 | 11.6,14,19,30 | 11.8,13,20,29 |
| 3 | 11.2 | Uniformly Accelerated Motion | 11.35,40,48,55 | 11.36,39,50,57 | 11.33,42,47,56 | 11.34,41,49,55 | 11.37,46,53,60 | 11.38,43,54,59 |
| 4 | 11.4 | Curvilinear Motion (Rect. Comps) | 11.98,106,118,128 | 11.99,105,120,127 | 11.97,108,117,126 | 11.100,107,119,123 | 11.101,110,121,132 | 11.104,109,122,130 |
| 5 | 11.5 | Curvilinear Motion (Other Comp.) | 11.137,146,155,166 | 11.141,143,156,165 | 11.138,145,153,170 | 11.139,144,154,169 | 11.140,150,157,168 | 11.142,148,160,167 |
| 6 | 12.1 | Newton's Second Law and Linear Momentum | 12.7,16,28,47 | 12.8,15,30,46 | 12.5,23,29,45 | 12.6,20,31,44 | 12.13,22,32,54 | 12.14,21,33,52 |
| 7 | 12.2 | Angular Momentum and Orbital Mechanics | 12.57,69,78,88 | 12.58,6880,87 | 12.55,67,79,91 | 12.56,66,81,90 | 12.59,73,83,93 | 12.60,70,84,92, |
| 8 | | Review | | | | | | |
| 9 | | EXAM NUMBER ONE | | | | | | |
| 10 | 13.1 | Work and Energy, Power | 13.7,18,26,45 | 13.8,17,27,41 | 13.5,16,28,40 | 13.4,15,29,39 | 13.13,22,30,50 | 13.14,21,35,49 |
| 11 | 13.2 | Conservation of Energy | 13.58,65,72,80 | 13.59,64,74,79 | 13.55,67,70,82 | 13.57,62,71,81 | 13.60,63,73,84 | 13.61,66,75,83 |
| 12 | 13.2D | Application to Space Mechanics | 13.85,96,100,111 | 13.86,95,103,110 | 13.87,94,101,107 | 13.88,93,102,106 | 13.91,99,104,114 | 13.92,98,105,113 |
| 13 | 13.3 | Impulse and Momentum | 13.119,130,141,150 | 13.120,129,142,148 | 13.121,132,139,146 | 13.124,131,140,145 | 13.125,137,143,154 | 13.127,133,144,153 |
| 14 | 13.4 | Impact | 13.157,168,174,186 | 13.158,166,176,185 | 13.155,165,175,188 | 13.156,164,177,184 | 13.160,171,178,189 | 13.162,170,181,187 |
| 15 | 14.1 | Systems of Particles | 14.1,12,15,22 | 14.2,11,16,21 | 14.3,10,19,25 | 14.4,9,20,24 | 14.5,14,17,27 | 14.6,13,18,23 |
| 16 | 14.2 | Systems of Particles | 14.32,38,46,52 | 14.33,37,47,51 | 14.31,40,45,56 | 14.35,39,48,55 | 14.34,42,49,54 | 14.36,41,50,53 |
| 17 | 14.3 | Variable Systems of Particles | 14.61,72,77,87 | 14.62,70,78,86 | 14.59,71,80,94 | 14.60,69,83,94 | 14.63,75,92,98 | 14.65,73,93,97 |
| 18 | | EXAM NUMBER TWO | | | | | | |
| 19 | 15.1 | Translation, Rotation | 15.1,11,18,29 | 15.2,10,19,28 | 15.3,13,23,31 | 15.4,12,24,30 | 15.7,15,20,35 | 15.8,14,21,34 |
| 20 | 15.2 | General Plane Motion | 15.38,50,57,70 | 15.39,49,58,64 | 15.40,53,55,69 | 15.41,48,56,68 | 15.42,54,59,67 | 15.43,52,60,66 |
| 21 | 15.3 | Instantaneous Center | 15.76,83,88,98 | 15.77,82,90,95 | 15.74,87,89,97 | 15.75,86,94,96 | 15.73,85,92,104 | 15.81,84,93,101 |
| 22 | 15.4 | Acceleration in Plane Motion | 15.112,121,127,139 | 15.113,120,128,138 | 15.111,125,129,141 | 15.115,124,130,140 | 15.116,126,131,146 | 15.117,123,135,145 |
| 23 | 15.5 | Motion With Respect to a Rotating Frame | 15.150,163,168,178 | 15.151,162,169,177 | 15.152,161,166,175 | 15.155,160,167,174 | 15.156,159,172,180 | 15.157,158,173,179 |
| 24 | 15.6 | Motion of a Rigid Body in Space | 15.187,198,203,213 | 15.188,197,204,213 | 15.184,196,205,211 | 15.185,195,205,210 | 15.191,202,208,215 | 15.192,201,209,214 |
| 25 | 15.7 | Moving Reference Frames in Three Dimensions | 15.222,232,234,243 | 15.223,230,235,242 | 15.220,233,236,241 | 15.221,231,239,240 | 15.225,229,237,247 | 15.226,229,238,246 |
| 26 | 16.1 | Plane Motion of Rigid Bodies | 16.4,19,25,40 | 16.5,18,30,39 | 16.1,15,27,42 | 16.2,14,28,41 | 16.7,17,32,45 | 15.8,16,35,45 |
| 27 | 16.1 | Plane Motion of Rigid Bodies | 16.48,56,64,70 | 16.48,55,65,69 | 16.50,58,63,72 | 16.51,57,63,71 | 16.53,62,68,74 | 16.54,61,68,73 |
| 28 | | EXAM NUMBER THREE | | | | | | |
| 29 | 16.2 | Constrained Plane Motion | 16.76,86,98,116 | 16.77,85,99,107 | 16.78,87,102,109 | 16.79,84,103,108 | 16.81,91,100,110 | 16.82,90,101,106 |
| 30 | 16.2 | Constrained Plane Motion | 16.117,125,134,143 | 16.118,124,139,144 | 16.121,126,135,147 | 16.121,125,136,146 | 16.122,133,141,150 | 16.123,132,142,149 |
| 31 | 17.1 | Work and Energy | 17.1,19,25,40 | 17.6,18,26,39 | 17.2,23,27,37 | 17.7,17,30,36 | 17.14,22,28,42 | 17.15,21,34,41 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 32 | 17.2 | Impulse and Momentum | 17.55,71,80,89 | 17.59,70,81,88 | 17.52,72,79,95 | 17.54,69,82,90 | 17.56,75,84,93 | 17.57,73,85,92 |
| 33 | 17.3 | Eccentric Impact | 17.96,108,116,124 | 17.101,105,117,123 | 17.97, 107,119,122 | 17.98,109,120,121 | 17.99,111,113,130 | 17.100,110,114,125 |
| 34 | 18.1 | Momentum and Energy in Three Dimensions | 18.1,11,15,26 | 18.5,9,16,25 | 18.2,12,17,22 | 18.3,10,18,21 | 18.4,14,19,24 | 18.6,13,20,23 |
| 35 | 18.1 | Momentum and Energy in Three Dimensions | 18.30,41,50 | 18.29,42,49 | 18.32,39,54 | 18.31,40,53 | 18.36,45,52 | 18.35,46,51 |
| 36 | 18.2 | Motion in Three Dimensions | 18.55,68,71,78 | 18.56,67,72,77 | 18.57,66,75,80 | 18.58,65,76,79 | 18.60,70,73,82 | 18.64,69,74,81 |
| 37 | 18.2 | Motion in Three Dimensions | 18.86,95,102 | 18.85,96.101 | 18.88,93,104 | 18.87,94,103 | 18.92,97,106 | 18.91,98,105 |
| 38 | | EXAM NUMBER FOUR | | | | | | |
| 39 | 19.1 | Free Vibrations of Particles | 19.1,14,17,25 | 19.4,8,20,23 | 19.3,12,18,26 | 19.5,11,19,24 | 19.9,16,21,32 | 19.10,15,22,27 |
| 40 | 19.2 | Free Vibrations of Rigid Bodies | 19.38,45,57,64 | 19.41,44,59,63 | 19.37,51,55,68 | 19.41,50,56,67 | 19.40,47,58,66 | 19.43,46,61,65 |
| 41 | 19.3 | Energy Methods | 19.69,79,83,91 | 19.72,78,87,90 | 19.70,80,85,92 | 19.71,77,86,89 | 19.73,2,84,94 | 19.74,81,88,93 |
| 42 | 19.4 | Forced Vibrations | 19.101,107,115,122 | 19.102,106,116,121 | 19.99,110,113,125 | 19.100,105,114,123 | 19.103,111,118126 | 19.104,108,120,124 |

TABLE IV: SAMPLE ASSIGNMENT SCHEDULE FOR A COURSE IN DYNAMICS

This schedule includes all of the material of *VECTOR MECHANICS FOR ENGINEERS: DYNAMICS* with the exception of Sections 11.7, 11.8, 12.11–12.13, 18.9–18.11 and 19.8–19.10.

75% OF THE PROBLEMS IN EACH OF THE FOLLOWING LISTS USE SI UNITS AND 25% U.S. CUSTOMARY UNITS

ANSWERS TO ALL OF THESE PROBLEMS ARE GIVEN IN THE BACK OF THE BOOK

| Period | Sections | Topics | List 1a | List 2a | List 3a | List 4a |
|---|---|---|---|---|---|---|
| 1 | 11.1 | Introduction | | | | |
| 2 | 11.1 | Rectilinear Motion | 11.3,10,15,27 | 11.4,9,18,26 | 11.5,12,16,24 | 11.7,11,17,21 |
| 3 | 11.2 | Uniformly Accelerated Motion | 11.35,40,51,55 | 11.36,39,52,57 | 11.33,45,47,56 | 11.34,44,49,55 |
| 4 | 11.4 | Curvilinear Motion (Rect. Comps) | 11.98,106,118,131 | 11.99,105,120,129 | 11.102,108,117,126 | 11.103,107,119,123 |
| 5 | 11.5 | Curvilinear Motion (Other Comp.) | 11.137,146,158,166 | 11.141,143,159,165 | 11.138,149,153,170 | 11.139,147,154,169 |
| 6 | 12.1 | Newton's Second Law and Linear Momentum | 12.7,16,28,49 | 12.8,15,30,48 | 12.9,23,29,45 | 12.10,20,31,44 |
| 7 | 12.2 | Angular Momentum and Orbital Mechanics | 12.57,69,82,88 | 12.58,68,85,87 | 12.55,72,79,91 | 12.56,71,81,90 |
| 8 | | Review | | | | |
| 9 | | EXAM NUMBER ONE | | | | |
| 10 | 13.1 | Work and Energy, Power | 13.7,18,26,52 | 13.8,17,27,51 | 13.11,16,28,40 | 13.12,15,29,39 |
| 11 | 13.2 | Conservation of Energy | 13.58,65,76,80 | 13.59,64,77,79 | 13.55,69,70,82 | 13.57,68,71,81 |
| 12 | 13.2D | Application to Space Mechanics | 13.85,96,100,109 | 13.86,95,103,108 | 13.89,94,101,107 | 13.90,93,102,106 |
| 13 | 13.3 | Impulse and Momentum | 13.119,130,141,152 | 13.120,129,142,151 | 13.126,132,139,146 | 13.128,131,140,145 |
| 14 | 13.4 | Impact | 13.157,168,179,186 | 13.158,166,180,185 | 13.155,172,175,188 | 13.156,169,177,184 |
| 15 | 14.1 | Systems of Particles | 14.1,12,15,28 | 14.2,11,16,26 | 14.7,10,19,25 | 14.8,9,20,24 |
| 16 | 14.2 | Systems of Particles | 14.32,38,51,52 | 14.33,37,51,52 | 14.31,44,45,56 | 14.35,43,48,55 |
| 17 | 14.3 | Variable Systems of Particles | 14.61,72,77,96 | 14.62,70,78,95 | 14.64,71,80,94 | 14.66,69,83,94 |
| 18 | | EXAM NUMBER TWO | | | | |
| 19 | 15.1 | Translation, Rotation | 15.1,11,18,33 | 15.2,10,19,32 | 15.5,13,23,31 | 15.6,12,24,30 |
| 20 | 15.2 | General Plane Motion | 15.38,50,61,70 | 15.39,49,62,64 | 15.40,51,55,69 | 15.41,50,56,68 |
| 21 | 15.3 | Instantaneous Center | 15.76,83,88,103 | 15.77,82,90,102 | 15.78,87,89,97 | 15.79,86,94,96 |
| 22 | 15.4 | Acceleration in Plane Motion | 15.112,121,132,139 | 15.113,120,133,138 | 15.111,122,129,141 | 15.115,122,130,140 |
| 23 | 15.5 | Motion With Respect to a Rotating Frame | 15.150,163,168,176 | 15.151,162,169,181 | 15.153,161,166,175 | 15.154,160,167,174 |
| 24 | 15.6 | Motion of a Rigid Body in Space | 15.187,198,206,213 | 15.188,197,207,213 | 15.184,199,205,211 | 15.185,200,205,210 |
| 25 | 15.7 | Moving Reference Frames in Three Dimensions | 15.222,232,234,245 | 15.223,230,235,244 | 15.224,233,236,241 | 15.227,231,239,240 |
| 26 | 16.1 | Plane Motion of Rigid Bodies | 16.4,19,25,44 | 16.5,18,30,43 | 16.9,15,27,42 | 16.10,14,28,41 |
| 27 | 16.1 | Plane Motion of Rigid Bodies | 16.48,56,66,70 | 16.48,55,67,69 | 16.50,60,63,72 | 16.51,59,63,71 |
| 28 | | EXAM NUMBER THREE | | | | |

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|---|---|---|---|---|---|---|
| 29 | 16.2 | Constrained Plane Motion | 16.76,86,98,114 | 16.77,85,99,113 | 16.80,87,102,109 | 16.83,84,103,108 |
| 30 | 16.2 | Constrained Plane Motion | 16.117,125,137,143 | 16.118,124,138,144 | 16.121,129,135,147 | 16.121,128,136,146 |
| 31 | 17.1 | Work and Energy | 17.1,19,25,46 | 17.6,18,26,45 | 17.11,23,27,37 | 17.12,17,30,36 |
| 32 | 17.3 | Impulse and Momentum | 17.55,71,83,89 | 17.59,70,86,88 | 17.52,75,79,95 | 17.54,74,82,90 |
| 33 | 17.3 | Eccentric Impact | 17.96,108,116,128 | 17.101,105,117,127 | 17.102,107,119,122 | 17.103,109,120,121 |
| 34 | 18.1 | Momentum and Energy in Three Dimensions | 18.1,11,15,28 | 18.5,9,16,27 | 18.7,12,17,22 | 18.8,10,18,21 |
| 35 | 18.1 | Momentum and Energy in Three Dimensions | 18.30,44,50 | 18.29,45,49 | 18.36,39,54 | 18.35,40,53 |
| 36 | 18.2 | Motion in Three Dimensions | 18.55,68,71,84 | 18.56,67,72,82 | 18.60,66,75,80 | 18.64,65,76,79 |
| 37 | 18.2 | Motion in Three Dimensions | 18.86,99,102 | 18.85,100.101 | 18.91,93,104 | 18.90,94,103 |
| 38 | | EXAM NUMBER FOUR | | | | |
| | | | | | | |
| 39 | 19.1 | Free Vibrations of Particles | 19.1,14,17,31 | 19.4,8,20,28 | 19.5,12,18,26 | 19.7,11,19,24 |
| 40 | 19.2 | Free Vibrations of Rigid Bodies | 19.38,45,60,64 | 19.41,44,62,63 | 19.37,49,55,68 | 19.41,48,56,67 |
| 41 | 19.3 | Energy Methods | 19.69,79,83,96 | 19.72,78,87,95 | 19.75,80,85,92 | 19.76,77,86,89 |
| 42 | 19.4 | Forced Vibrations | 19.101,107,117,122 | 19.102,106,119,121 | 19.99,112,113,125 | 19.100,109,114,123 |