

## *Chapter 6*

# **Introduction to Dynamics**

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## 6.1 Dynamics

*Dynamics* is the study of bodies in motion. Dynamics is concerned with describing motion and explaining its causes. The general field of dynamics consists of two major areas: kinematics and kinetics. Each of these areas can be further divided to describe and explain linear, angular, or general motion of bodies. The fundamental concepts in dynamics are space (relative position or displacement), time, mass, and force. Other important concepts include velocity, acceleration, torque, moment, work, energy, power, impulse, and momentum.

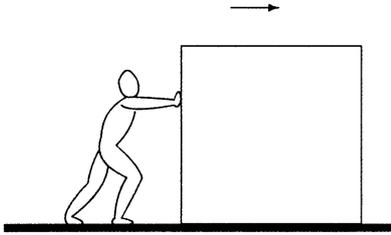
The broad definitions of basic terms and concepts in dynamics will be introduced in this chapter. The details of kinematic and kinetic characteristics of moving bodies will be covered in the following chapters.

## 6.2 Kinematics and Kinetics

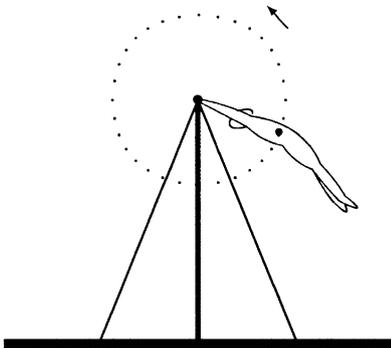
The field of *kinematics* is concerned with the description of geometric and time-dependent aspects of motion without dealing with the forces causing the motion. Kinematic analyses are based on the relationships between displacement, velocity, and acceleration vectors. These relationships appear in the form of differential and integral equations.

The field of *kinetics* is based on kinematics, and it incorporates into the analyses the effects of forces and torques that cause the motion. Kinetic analyses utilize Newton's second law of motion that can take various mathematical forms. There are a number of different approaches to the solutions of problems in kinetics. These approaches are based on the equations of motion, work and energy methods, and impulse and momentum methods. Different methods may be applied to different situations, or depending on what is required to be determined. For example, the equations of motion are used for problems requiring the analysis of acceleration. Energy methods are suitable when a problem requires the analysis of forces related to changes in velocity. Momentum methods are applied if the forces involved are impulsive, which is the case during impact and collision.

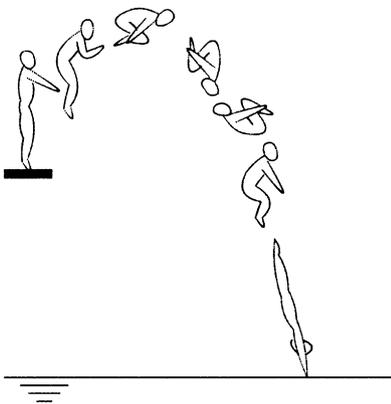
There is also the field of *kinesiology* that is related to the study of human motion characteristics, joint and muscle forces, and neurological and other factors that may be important in studying human motion. The term "kinesiology" is not a mechanical but a medical term. It is commonly used to refer to the biomechanics of human motion.



**Fig. 6.1** An object subjected to externally applied forces



**Fig. 6.2** Method of sections



**Fig. 6.3** Internal forces and moments

### 6.3 Linear, Angular, and General Motions

To study both kinematics and kinetics in an organized manner, it is a common practice to divide them into branches according to whether the motion is translational, rotational, or general. *Translational* or *linear motion* occurs if all parts of a body move the same distance at the same time and in the same direction. For example, if a block is pushed on a horizontal surface, the block will undergo translational motion only (Fig. 6.1). Another typical example of translational motion is the vertical motion of an elevator in a shaft. It should be noted, however, that linear motion does not imply movement along a straight line. In a given time interval, an object may translate in one direction, and it may translate in a different direction during a different time interval.

*Rotational* or *angular motion* occurs when a body moves in a circular path such that all parts of the body move in the same direction through the same angle at the same time. The angular motion occurs about a central line known as the *axis of rotation*, which lies perpendicular to the plane of motion. For example, for a gymnast doing giant circles, the center of gravity of the gymnast may undergo rotational motion with the centerline of the bar acting as the axis of rotation of the motion (Fig. 6.2).

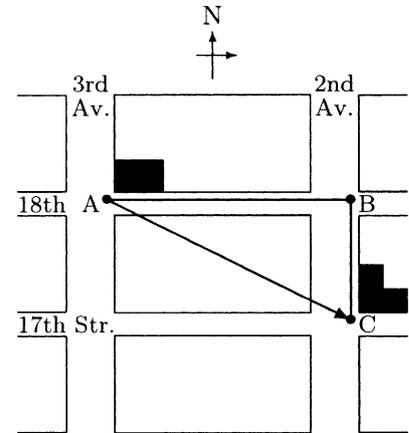
The third class of motion is called *general motion* which occurs if a body undergoes translational and rotational motions simultaneously. It is more complex to analyze motions composed of both translation and rotation as compared to a pure translational or a pure rotational motion. The diver illustrated in Fig. 6.3 is an example of a body undergoing general motion. Most human body segmental motions are of the general type. For example, while walking, the lower extremities both translate and rotate. The branch of kinematics that deals with the description of translational motion is known as *linear kinematics* and the branch that deals with rotational motion is *angular kinematics*. Similarly, the field of kinetics can be divided into *linear* and *angular kinetics*.

Linear movements are direct consequences of applied forces. The linear motion of an object occurs in the direction of the net force acting on the object. On the other hand, angular movements are due to the rotational effects of applied forces, which are known as torques. There are linear and angular quantities defined to analyze linear and angular motions, respectively. For example, there are linear and angular displacements, linear and angular velocities, and linear and angular accelerations. It is important to note however that linear and angular quantities are not mutually independent. That is, if angular quantities are known, then linear quantities can also be determined, and vice versa.

## 6.4 Distance and Displacement

In mechanics, *distance* is defined as the total length of the path followed while moving from one point to another, and *displacement* is the length of the straight line joining the two points along with some indication of direction involved. Distance is a scalar quantity (has only a magnitude) and displacement is a vector quantity (has both a magnitude and a direction).

To understand the differences between distance and displacement, consider a person who lives in an apartment building located at the corner of Third Avenue and 18th Street, and walks to work in a building located at the corner of Second Avenue and 17th Street in New York City. In Fig. 6.4, A represents the corner of Third Avenue and 18th Street, B represents the corner of Second Avenue and 18th Street, and C represents the corner of Second Avenue and 17th Street. Every morning this person walks toward the east from A to B, and then toward the south from B to C. Assume that the length of the straight line between A and B is 100 m, and between B and C is 50 m. Therefore, the total distance the person walks every morning is 150 m. On the other hand, the door-to-door south-easterly displacement of the person is equal to the length of the straight line joining A and C, which is  $\sqrt{(100)^2 + (50)^2} = 112$  m.



**Fig. 6.4** Distance versus displacement

## 6.5 Speed and Velocity

While the terms speed and velocity are used interchangeably in ordinary language, they have distinctly different meanings in mechanics. *Velocity* is defined as the time rate of change of position. Velocity is a vector quantity having both a magnitude and a direction. *Speed* is a scalar quantity equal to the magnitude of the velocity vector.

## 6.6 Acceleration

*Acceleration* is defined as the time rate of change of velocity, and is a vector quantity. Although the term “acceleration” is more commonly used to describe situations where speed increases over time and the term “deceleration” is used to indicate decreasing speed over time, the mathematical definitions of the two are the same.

## 6.7 Inertia and Momentum

*Inertia* is the tendency of an object to maintain its state of rest or uniform motion. Inertia can also be defined as the resistance to the change in motion of an object. The more inertia an object has, the more difficult it is to start moving it from rest or to change its state of motion. The greater the mass of the object, the greater its inertia. For example, a truck has a greater inertia than a passenger car because of the difference in their mass. If both of them are traveling at the same speed, it is always more difficult to stop the truck as compared to the car.

Like inertia, *momentum* is a tendency to resist changes in the existing state of motion and is defined as the product of mass and velocity. Only moving objects have momentum, whereas every object—stationary or moving—has an inertia. If two moving objects having the same mass are considered, then the one with higher speed has the greater momentum. If two moving objects having the same speed are considered, then the one with higher mass has the greater momentum.

## 6.8 Degree of Freedom

*Degree of freedom* is an expression that describes the ability of an object to move in space. A completely unrestrained object, such as a ball, has six degrees of freedom (three related to translational motion along three mutually perpendicular axes and three related to rotational motion about the same axes). The human hip joint has three degrees of freedom because it enables the lower extremity to rotate about one axis and undergo angular movements in two planes. On the other hand, the elbow and forearm system has two degrees of freedom because it allows the lower arm to rotate about one axis and undergo angular movement in one plane.

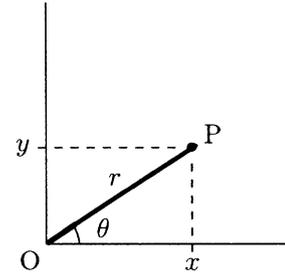
## 6.9 Particle Concept

The “particle” concept in mechanics is rather a hypothetical one. It undermines the size and shape of the object under consideration, and assumes that the object is a particle with a mass equal to the total mass of the object and located at the center of gravity of the object. In some problems, the shape of the object under investigation may not be pertinent to the discussion of certain aspects of its motion. This is particularly true if the object is undergoing a translational motion only. For example, what is significant for a person pushing a wheelchair is the total mass of the wheelchair, not its size or shape. Therefore, the wheelchair may be treated as a particle with a mass

equal to the total mass of the wheelchair, and proceed with relatively simple analyses. The size and shape of the object may become important if the object undergoes a rotational motion.

## 6.10 Reference Frames and Coordinate Systems

To be able to describe the motion of a body properly, a *reference frame* must be adopted. The *rectangular* or *Cartesian coordinate system* that is composed of three mutually perpendicular directions is the most suitable reference frame for describing linear movements. The axes of this system are commonly labeled with  $x$ ,  $y$ , and  $z$ . For two-dimensional problems, the number of axes may be reduced to two by eliminating the  $z$  axis (Fig. 6.5).



**Fig. 6.5** Rectangular  $(x, y)$  and polar  $(r, \theta)$  coordinates of a point

Another commonly used reference frame is the *polar coordinate system*, which is better suited for analyzing angular motions. As shown in Fig. 6.5, the polar coordinates of a point  $P$  are defined by parameters  $r$  and  $\theta$ .  $r$  is the distance between the origin  $O$  of the coordinate frame and point  $P$ , and  $\theta$  is the angle line  $OP$  makes with the horizontal. The details of polar coordinates will be provided in later chapters.

## 6.11 Prerequisites for Dynamic Analysis

The prerequisites for dynamic analysis are vector algebra, differential calculus, and integral calculus. Vector algebra is reviewed in Appendix B. The principles of differential and integral calculus are provided in Appendix C, along with the definitions and properties of commonly encountered functions that form the basis of calculus. Appendices B and C must be reviewed before proceeding to the following chapters. Also important in dynamic analyses are the properties of force and torque vectors as covered in Chaps. 2 and 3, respectively. It should be noted that the static analyses covered in Chaps. 4 and 5 are specific cases of dynamic analyses for which acceleration is zero.

## 6.12 Topics to Be Covered

Chaps. 6 through 11 constitute the second part of this textbook, which is devoted to the analyses of moving systems. In Chap. 7, mathematical definitions of displacement, velocity, and acceleration vectors are introduced, kinematic relationships between linear quantities are defined, uniaxial and biaxial motion analyses are discussed, and the concepts introduced are applied

to problems of sports biomechanics. Linear kinetics is studied in Chap. 8. Solving problems in kinetics using the equations of motion and work and energy methods are discussed in Chap. 8. Angular kinematics and kinetics are covered in Chaps. 9 and 10, respectively, and the concepts and procedures introduced are applied to investigate some of the problems of biomechanics. Topics such as impulse, momentum, impact, and collision are covered in Chap. 11.