FUNDAMENTALS OF MECHANICS

FM.1 WHAT IS MECHANICS?
Mechanics may be defined as that science which describes and predicts the conditions of rest or motion of bodies under the action of forces. It is divided into three parts: mechanics of rigid bodies, mechanics of deformable bodies and mechanics of fluids.

The mechanics of rigid bodies is subdivided into statics and dynamics, the former dealing with bodies at rest, the latter with bodies in motion.

Mechanics is a physical science, since it deals with the study of physical phenomena. Mechanics is the foundation of most engineering sciences and is indispensable prerequisite to their study. The purpose of mechanics is to explain and predict physical phenomena and thus to lay the foundations for engineering applications.

FM.2 FUNDAMENTAL CONCEPTS AND PRINCIPLES
The basic concepts used in mechanics are: space, time, mass, and force. These concepts cannot be truly defined; they should be accepted on the basis of our intuition and experience and used as a mental frame of reference for our study of mechanics.

The concept of space is associated with the notion of the position of a point $P$. Three lengths measured from a certain reference planes having a common point called origin in three given directions may define the position of P. These lengths are known as the coordinates of $P$. The space is assumed to be uniform.

To define an event, it is not sufficient to indicate its position in space. The time of event should also be given.

The concept of mass is used to characterize and compare bodies on the basis of certain fundamental mechanical experiments. Two bodies of the same mass, for example, will be attracted by the earth in the same manner; they will also offer the same resistance to a change in translational motion.
A force represents the action of one body in another. It may be exerted by actual contact or at a distance, as in the case of gravitational forces and magnetic forces. A force is characterized by its point of application, its magnitude, and its direction; a force is represented by a vector.

In newtonian mechanics, space, time, and mass are absolute concepts, independent of each other. (This is not true in relativistic mechanics), where the time of event depends upon its position, and where the mass of a body varies with its velocity.) On the other hand, the concept of force is not independent of the other three. Indeed, one of the fundamental principles of newtonian mechanics listed below indicates that the resultant force acting on a body is related to the mass of the body and the manner in which its velocity varies with time.

We shall study the conditions of rest or motion of particles and rigid bodies in terms of the four basic concepts we have introduced. By particle we mean a very small amount of matter, which may be assumed to occupy a single point in space. A rigid body is a combination of a large number of particles occupying fixed positions with respect to each other. The study of the mechanics of particles is obviously a prerequisite to that of rigid bodies. Besides, the results obtained for a particle may be used directly in a large number of problems dealing with the conditions of rest or motion of actual bodies.

The study of elementary mechanics rests on six fundamental principles based on experimental evidence:

The Parallelogram Law for the Addition of Forces. This states that two forces acting on a particle may be replaced by a single force, called their resultant, obtained by drawing the diagonal of the parallelogram, which has sides equal to the given forces.

The Principle of Transmissibility. This states that the conditions of equilibrium or of motion of a rigid body will remain unchanged if a force acting at a given point of the rigid body is replaced by a force of the same magnitude and the same
direction, but acting at a different point, provided that the two forces have the same line of action.

**Newton’s Three Fundamental Laws:**

1. If the resultant force acting on a particle is zero, the particle will remain at rest (if originally at rest) or will move with constant speed in a straight line (if originally in motion)

2. If the resultant force acting on a particle is zero, the particle will have an acceleration proportional to the magnitude of the resultant and in the direction of this resultant force, i.e.

   \[ \mathbf{F} = m \mathbf{a} \quad (F.1) \]

3. The forces of action and reaction between bodies in contact have the same magnitude, same line of action, and opposite sense.

**Newton’s Law of Gravitation.** This states that two particles of mass \( M \) and \( m \) are mutually attracted with equal and opposite forces \( \mathbf{F} \) and \( -\mathbf{F} \) (Fig. F.1) of magnitude \( F \) given by the formula

   \[ F = G \frac{Mm}{r^2} \quad (F.2) \]

   where \( r \) – distance between the two particles

   \( G \) – universal constant called the *constant of gravitation.*

**FM.3 BASIC DIMENSIONS AND UNITS OF MECHANICS**

In mechanics, we wish to examine quantitatively certain aspects of the mechanical actions of bodies and then to communicate our findings clearly. To do this, we must establish abstractions to describe those manifestations of the body that we are interested in. These artificial concepts are called *dimensions.*

The dimensions that we first pick, which are independent of all other dimensions, are termed *primary or basic dimensions,* and the ones that are then developed in terms of basic dimensions we call *secondary dimensions.* One of the many
possible sets of basic dimensions that we could use in our study of mechanics includes the dimensions of length, time and mass.

Length – a concept for describing size quantitatively. In order to determine the size of an object we must place a second object of known size next to it. This second object is called pattern or standard. A straight line scratched on a metal bar that is kept at uniform thermal and physical conditions used to serve as this simple standard for a long time.

Time – a concept for ordering the flow of events. For an accurate description of “when has happened an event” we must find an action, which appears to be completely repeatable. Then we can order the events under study by counting the number of these repeatable actions and fractions thereof that occur while the events transpire. The rotation of the earth serves as good measure of time, but we need smaller units in most our work in engineering and thus generally tie events to the second, which is an action repeatable 86 400 times a day.

Mass – a property of matter. Mass is property of matter that can be determined from two different actions of bodies. To study the first action, suppose we consider two rigid bodies of entirely different composition, size shape, color, etc. If we attach the bodies to identical springs, each spring will extend some distance as a result of attraction of gravity for the bodies. Even if we rise the springs to a new height above the earth’s surface, thus lessening the deformation of the springs, the extensions induced by the pull of gravity will be the same for both bodies. Thus we conclude that the bodies have an equivalent property. This property of each body that manifests itself in the amount of gravitational attraction we call mass.

The equivalence of these same bodies can be indicated in yet a second action. If we move both bodies an equal distance downward, by stretching each spring, and then release them at the same time, they will begin to move in an identical manner (except for small variations due to differences in wind friction and local deformations of the bodies). We have imposed, in effect, the same mechanical
disturbance on each body and we have elicited the same dynamical response. Hence, despite many obvious differences, the two bodies again show equivalence.

*The property of mass, then, characterizes a body both in the action of gravitational attraction and in the response to a mechanical disturbance.*

To communicate this property quantitatively, we may choose some convenient body and compare other bodies to it in the two above-mentioned actions. For example, we can find the mass of a body by comparing the extension of a spring it causes with that of a given body at the same location on the earth.

*International System of Units (SI Units).* In this system, which will be in universal use the base units are:

- **Meter** (m) for a measure length (L) property,
- **Second** (s) for a measure time (t) flow,
- **Kilogram** (kg) for a measure mass (M) of a body.

All three are arbitrarily defined. The second, which is supposed to represent the 1/86 400 part of the mean solar day, is actually defined as the duration of 9 192 631 770 cycles of the radiation associated with a specified transition of the cesium atom. The meter, originally intended to represent one-tenth-millionth of the distance from the equator to the pole, is now defined as 1 650 763, 73 wavelengths of the orange-red line of krypton 86. The kilogram, which is approximately equal to the mass of 0.001 m³ of water, is actually defined as the mass of platinum standard kept at the International Bureau of Weights and Measures at Sèvres near Paris, France.

The SI units are said to form an *absolute* system of units. This means that the three base units chosen are independent of the location where measurements are made. The meter, the kilogram, and the second may be used anywhere on the earth; they may be even used on another planet. They will always have the same significance.
In physics as well as in engineering sciences there is a need to use secondary
dimensional quantities. The units of these quantities are referred to as *derived
units*. For example the unit of force is derived unit. It is called the *newton* (N) and
is defined as the force which gives an acceleration of \(1\text{m/s}^2\) to a mass of 1 kg.
From Eq (F.1) we write
\[
1 \text{ N} = (1 \text{ kg})(1\text{m/s}^2) = 1 \text{ kg}\cdot\text{m/s}^2
\]

Bibliography