Chapter 1 - Fundamental Concepts and Principles

Reading: Chapter 1, Pgs. 3-31

1-1

Introduction to Mechanics

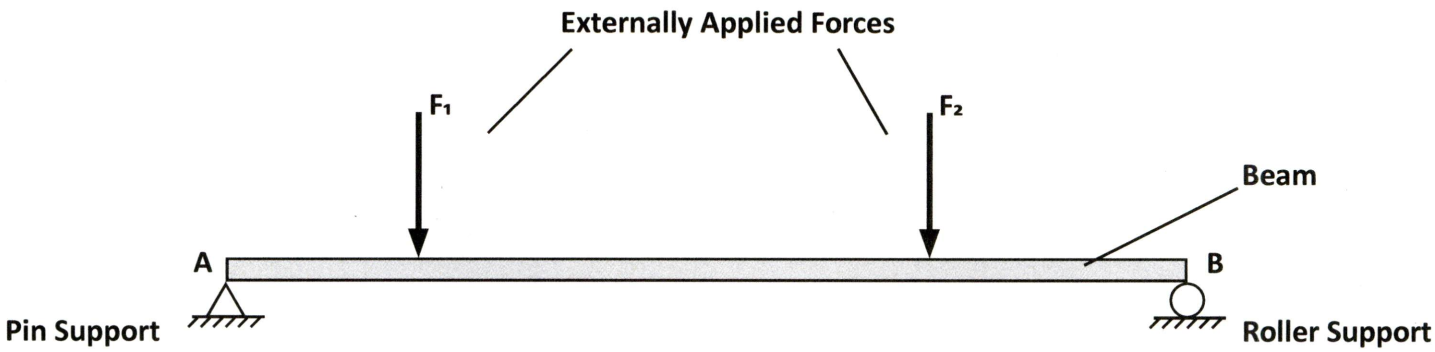
Mechanics - branch of physical sciences that deals with the state of rest or motion of bodies under the action of forces.

Mechanics

1. Statics
2. Dynamics
3. Strength of Materials

Statics

Equilibrium of bodies under the action of balanced forces.

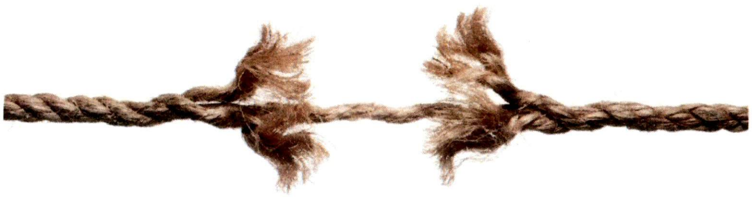


Dynamics

Motion of bodies under the action of unbalanced forces.

Strength of Materials

Relationships among the external forces applied to the bodies, the resulting stresses (intensity of internal forces), and deformation (change of size or shape). The determination of the proper sizes of structural members to satisfy strength and deformation requirements are also important topics.



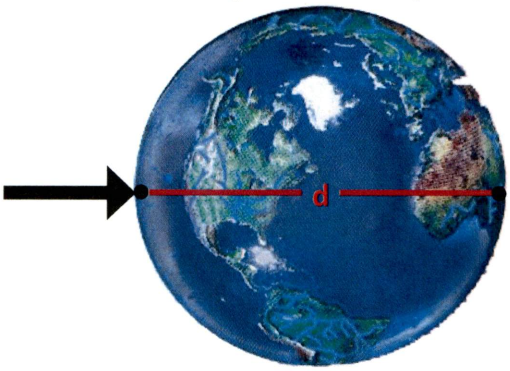
Assumptions

Statics and Dynamics

All bodies are assumed to be perfectly rigid.

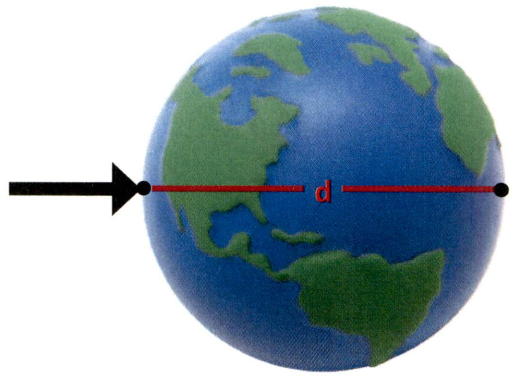
A rigid body is a solid in which the distance between any two points in the body remain unchanged.

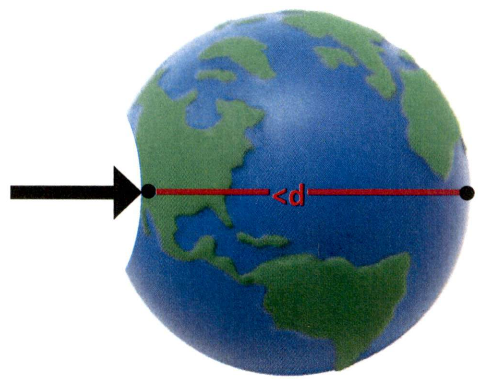
Rigid Body
(Earth Marble)



The distance (d) between the two points shown remains unchanged regardless of the force applied to the surface. The force causes no deformation on the rigid body.

Not Rigid Body
(Earth Foam Stress Ball)





Strength of Materials

Deformation of structural members becomes very important because the concerns are the strength and stiffness of structural or machine members.

Strength and stiffness are directly or indirectly related to the deformation, even if the deformation is very small.

1-2

The Nature of a Force

A force is any affect that may change the state of rest or motion of a body. The existence of a force can be observed by the effects that the force produces.

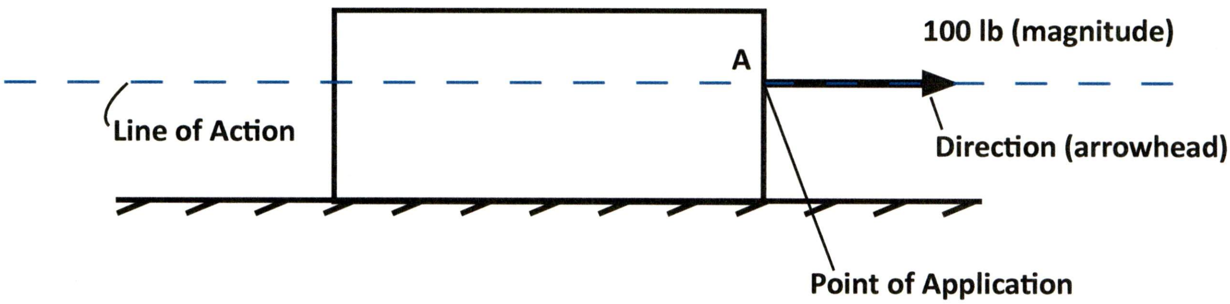
Force Applied by Direct Contact

Force Applied by Remote Action

Characteristics of a Force

A force can be defined completely by:

1. Magnitude - number with proper units
2. Direction - line of action with an arrowhead
3. Point of Application - point at which the force is exerted



1-3

Scalar and Vector Quantities

Scalar Quantities

Described completely by a magnitude.

Examples:

Value	U.S. Customary Units	S.I. Units
Length	feet (ft)	meter (m)
Area	ft x ft = ft^2	m x m = m^2
Volume	ft x ft x ft = ft^3	m x m x m = m^3
Speed	length / time = ft/s = fps	length / time = m/s
Mass	slug (lb x s^2/ft)	Kilogram (kg)
Time	Sec (s)	Sec (s)

Vector Quantities

Characterized by its magnitude (scalar), Direction (arrowhead/line of action), and point of application.

Vectors **do no add** like scalar quantities.

Vector quantities must be added **geometrically**, not algebraically.

Methods Used to Add Vectors:

Parallelogram Law

Triangle Rule

Rectangular Components

Graphically

Examples of Vector Quantities

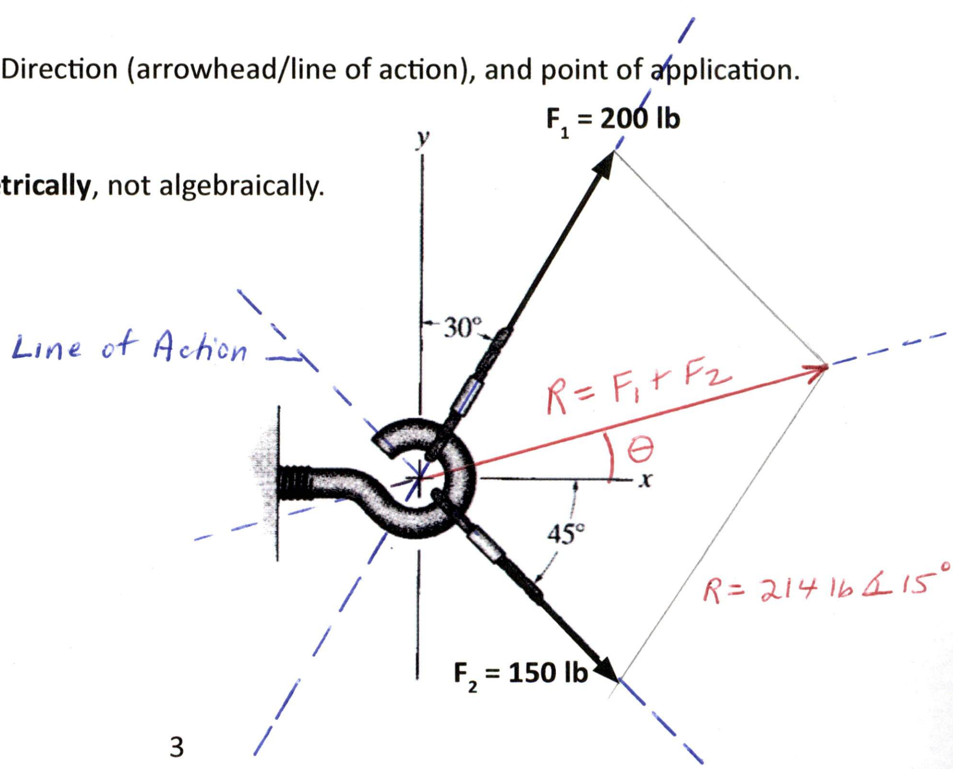
Force

Moment

Displacement

Velocity

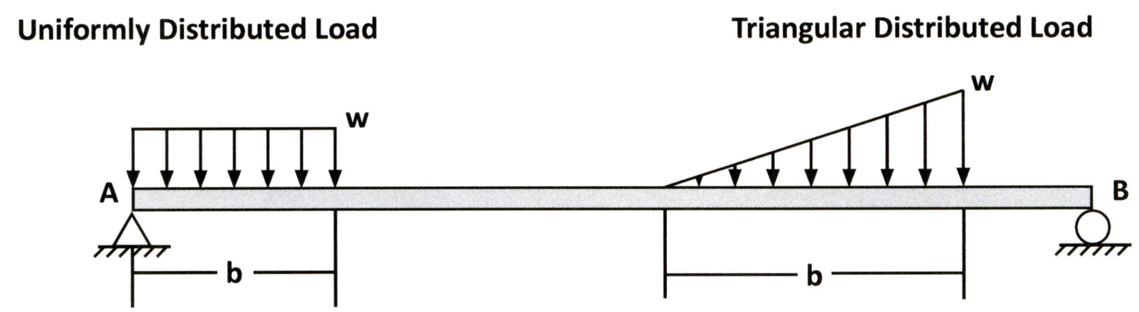
Acceleration



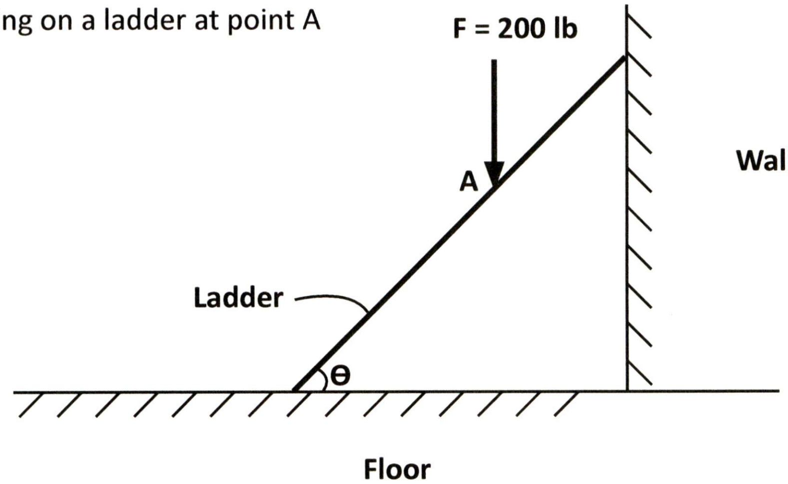
1-4
Types of Forces

Forces can be classified into the following types: Distributed and Concentrated Forces

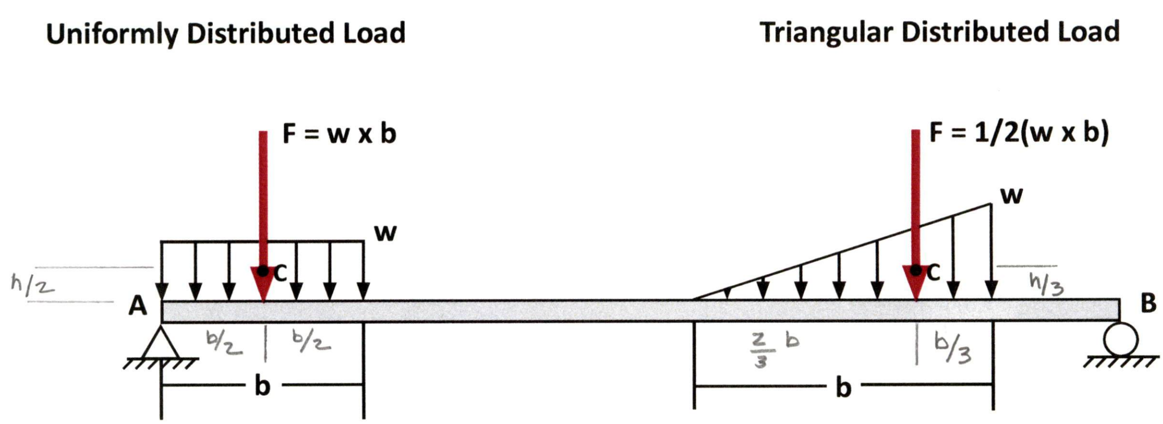
Distributed force is exerted on a line, over an area, or throughout an entire volume.
Example:



Concentrated force is an idealization in which a force is assumed to act at a point.
Example:
A 200 lb person standing on a ladder at point A



Equivalent concentrated force for a distributed load
w is the load intensity (force/length)
c = centroid of the shape

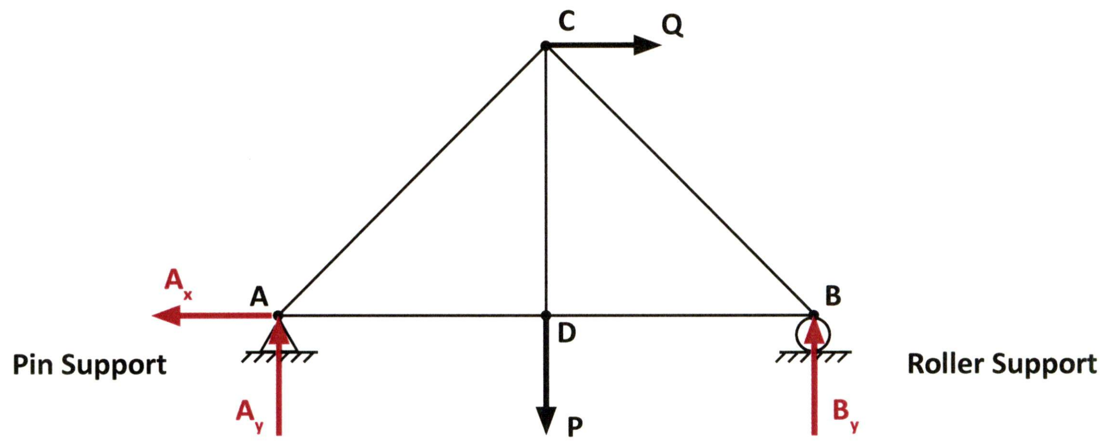


External and Internal Forces

External Force - force exerted on the body by another body.

Internal Force - structures formed by several connected components, the forces holding the component parts together are internal forces within the structure.

Example.
Truss - basic structure made up of triangles

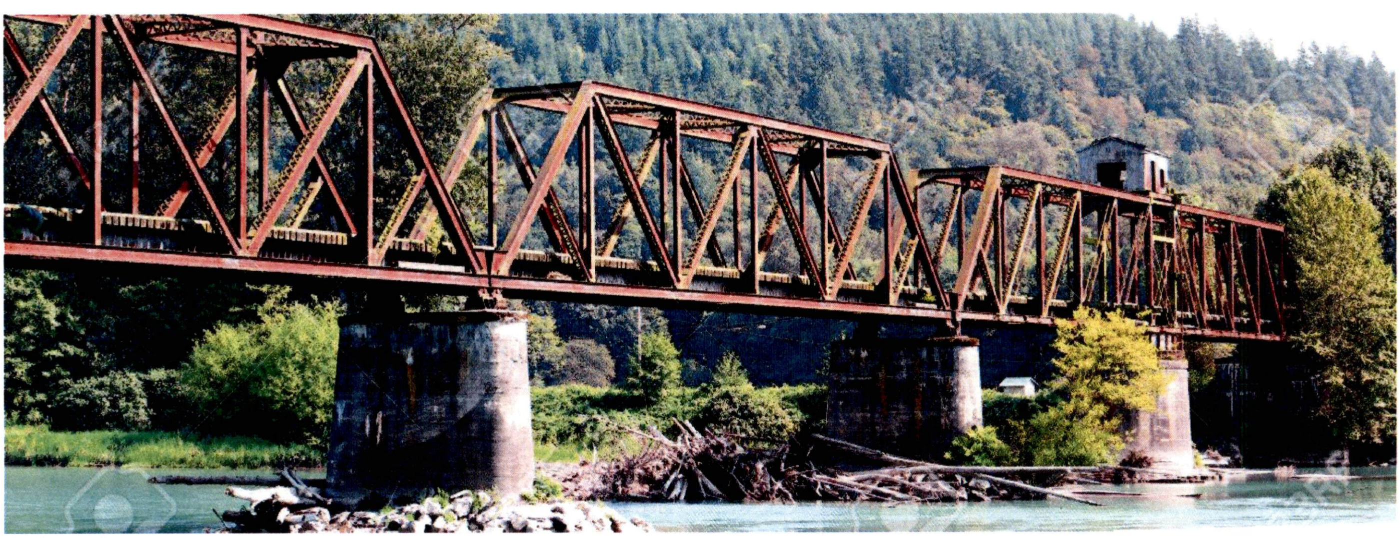


External Forces to the truss:

P and Q Applied Forces (loads)

A_x, A_y, B_y "Reactions" at the supports

Internal Forces are developed in the truss members due to the applied loads and the reactions. These internal forces are responsible for holding the truss together.

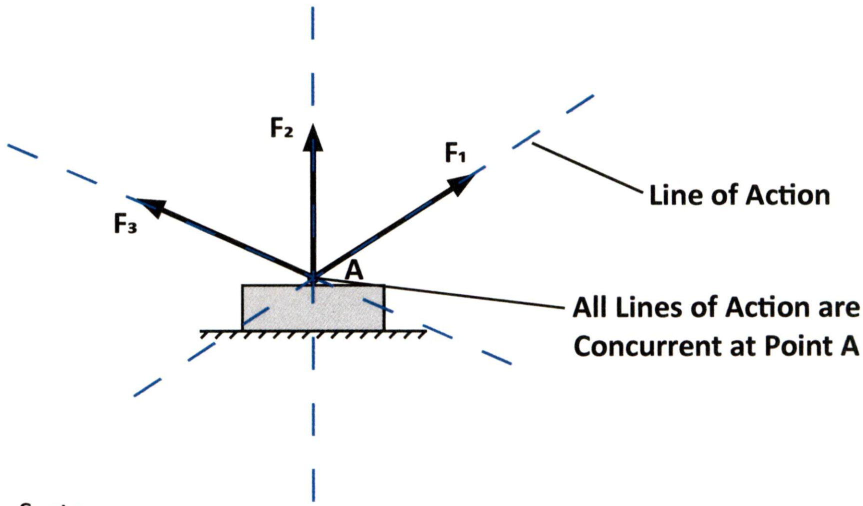


1-5

Types of Force Systems

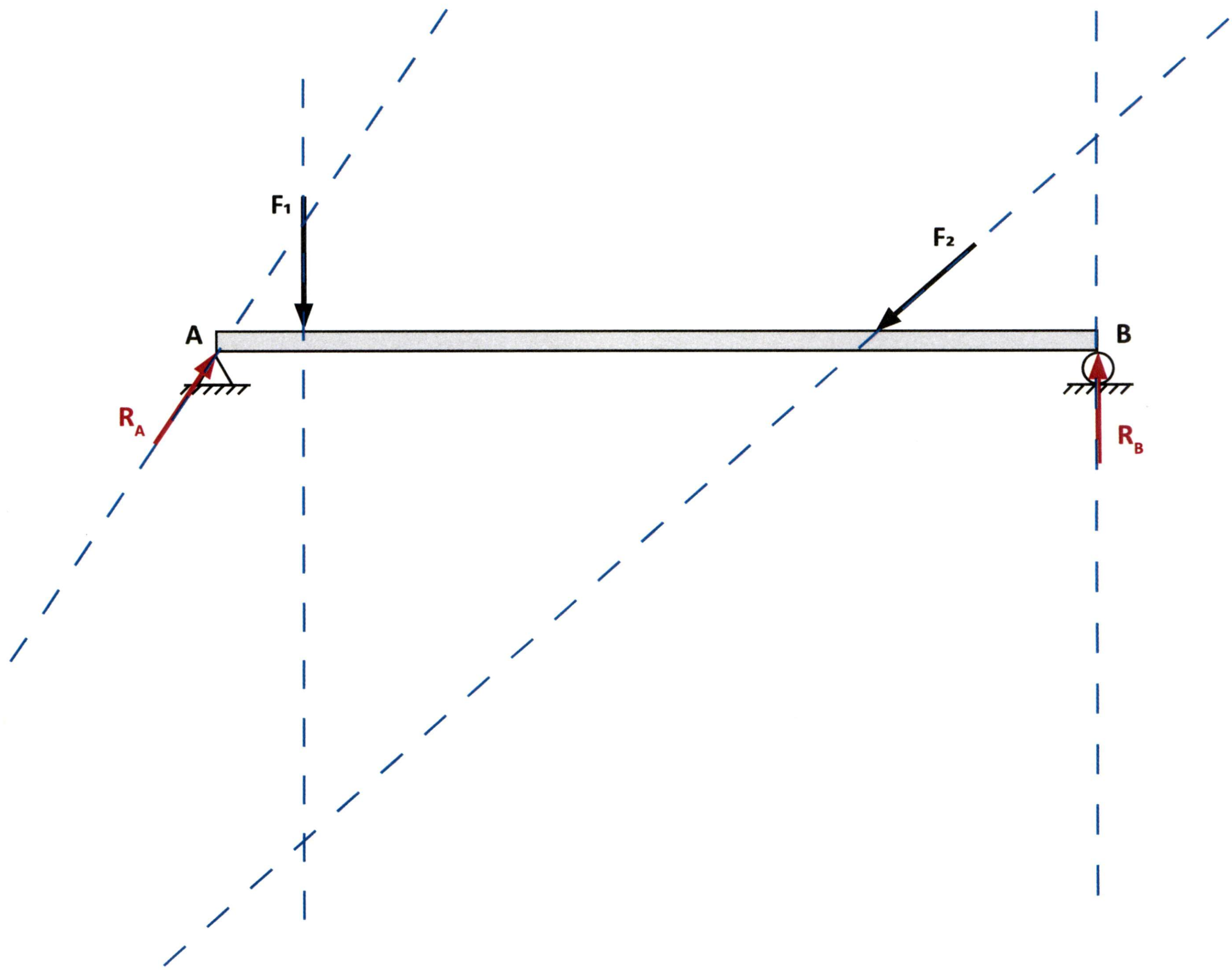
Concurrent Coplanar Force System

The lines of action of all the forces in the system pass through a common point and lie in the same plane.

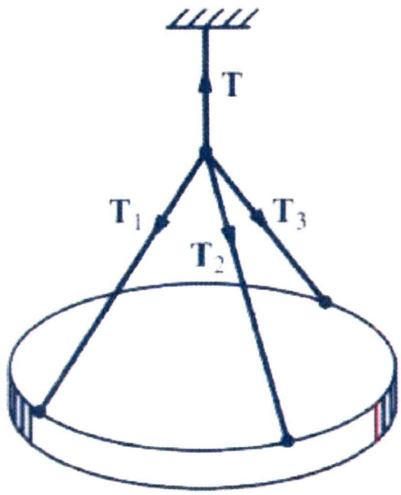


Nonconcurrent Coplanar Force System

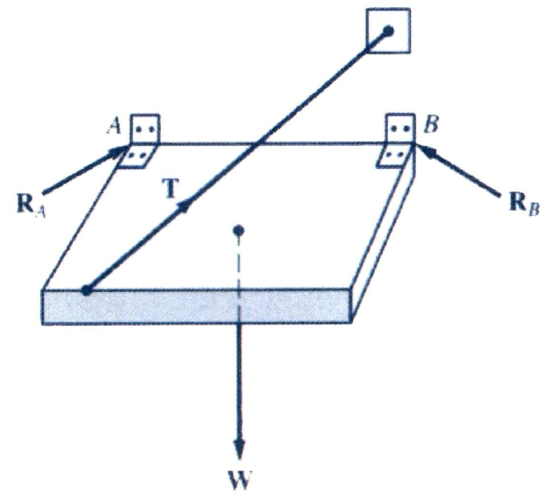
The lines of action of all the forces in the system lie in the same plane, but do not pass thorough a common point.



Concurrent Spatial Force System

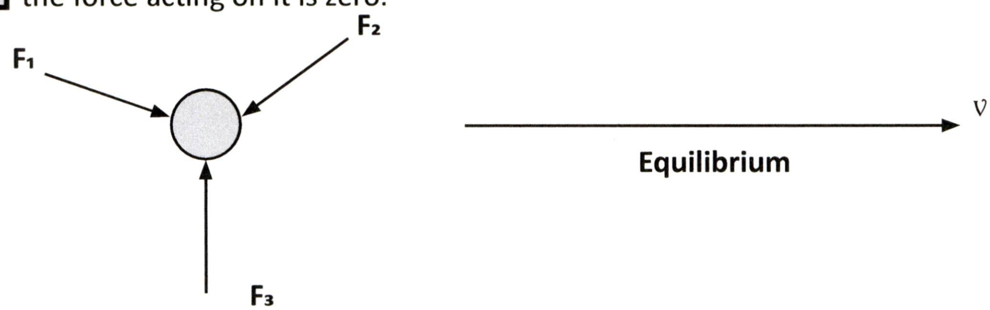


Nonconcurrent Spatial Force System

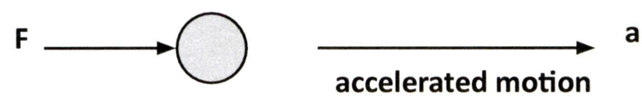


1-6
Newton's Laws

First Law A particle remains at rest or continues to move along a straight line with constant velocity if the force acting on it is zero.



Second Law If the force acting on a particle is not zero, the particle accelerates (changes velocity with respect to time) in the direction of the force, the magnitude of acceleration (the rate of change of velocity per unit time) is proportional to the magnitude of the force.



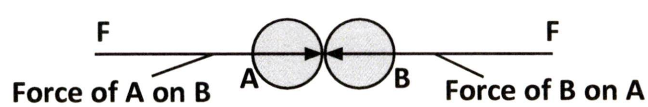
If F is applied to a particle of mass, m, this law may be expressed mathematically as:

$F = ma$

where F = the force acting on the particle
m = mass of the particle
a = the acceleration of the particle caused by the force

The second law is the basis for the study of DYNAMICS

Third Law The forces of action and reaction between two interactive bodies always have the same magnitudes and opposite directions.



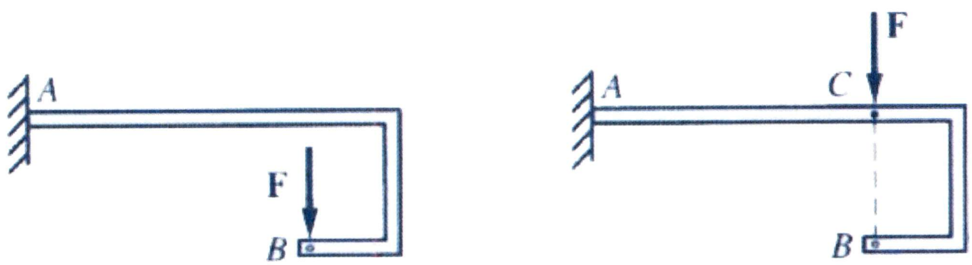
action - reaction

1-7

The Principle of Transmissibilty

The point of application of a force acting on a rigid body may be placed anywhere along its line of action, without altering the conditions of equilibrium or motion of the rigid body.

Note: The internal effect of a force on a body is dependent on its point of application. The principle of transmissibility does not apply if our concern is the internal force or deformation in the part labeled BC.



(a) (b)

1-8
System of Units

U.S. Customary Units Three Base Units: Length: foot (ft) Force: pound (lb) Time: second (s) The base unit pound is dependent on the gravitational attraction of the earth. The U.S. Units are a **Gravitational System**	S.I. Units Three Base Units: Length: foot (ft) Mass: kilogram (kg) Time: second (s) The base units are all independent. The S.I. Units are an **Absolute System**
The unit of mass, called the slug, is a derived unit: $F = m \times a$ $m = F / a$ $slug = lb/ft/s^2 = lb \times s^2/ft$ What is the weight of a mass of 1 slug? (on earth) $W = m \times g$ $= 1\ slug \times 32.2\ ft/s^2$ $= (1\ lb \times s^2/ft) \times 32.2\ ft/s^2$ $= 32.2\ lb$	The unit of force, called the newton (N) is a derived unit expressed in terms of the three base units: $F = m \times a$ $F = kg \times m/s^2 = 1$ Newton (N) What is the weight of a mass of 1 kg? (on earth) $W = m \times g$ $= 1\ kg \times 9.81\ m/s^2$ $= 9.81\ kg \times m/s^2 = 9.81\ N$

1-9
Unit Conversion

Changing units within a system is called **unit reduction**.
Reduce U.S. Customary unit to U.S. Customary Unit
Reduce S.I. unit to S.I. Unit

Changing units from one system to another system is called **unit conversion**.
Convert U.S. Customary Unit to S.I. Unit
Convert S.I. Unit to U.S. Customary Unit

Unit Conversion WILL NOT BE NEEDED to solve problems in CMGT 350.

TABLE 1–2 U.S. Customary Units and Their SI Equivalents

Quantity	*U.S. Customary Unit*	*SI Equivalent*
Length	ft	0.3048 m
	in.	25.40 mm
	mi	1.609 km
Mass	slug	14.59 kg
Force	lb	4.448 N
	kip	4.448 kN
Area	ft^2	0.0929 m^2
	$in.^2$	0.6452×10^{-3} m^2
Volume	ft^3	0.02832 m^3
	$in.^3$	16.39×10^{-6} m^3
Velocity	ft/s	0.3048 m/s
	mi/h (mph)	0.4470 m/s
	mi/h (mph)	1.609 km/h
Acceleration	ft/s^2	0.3048 m/s^2
Moment of a force	lb · ft	1.356 N · m
	lb · in.	0.1130 N · m
Pressure or stress	lb/ft^2 (psf)	47.88 Pa (pascal or N/m^2)
	$lb/in.^2$ (psi)	6.895 kPa (kN/m^2)
Spring constant	lb/ft	14.59 N/m
	lb/in.	175.1 N/m
Load intensity	lb/ft	14.59 N/m
	kip/ft	14.59 kN/m
Area moment of inertia	$in.^4$	0.4162×10^{-6} m^4
Work or energy	lb · ft	1.356 J (joule or N · m)
Power	lb · ft/s	1.356 W (watt or N · m/s)
	hp (1 horsepower = 550 ft · lb/s)	745.7 W (watt or N · m/s)

Examples:
Convert a velocity of 30 mph into its equivalent value in m/s.

$$v = \frac{30\,mi}{h} \times \frac{5280\,ft}{mi} \times \frac{0.3048\,m}{ft} \times \frac{h}{3600\,s} = 13.4\,m/s$$

Reduce v = 55 mi/h (mph) to ft/s (fps)

$$v = \frac{55\,mi}{h} \times \frac{5280\,ft}{mi} \times \frac{h}{3600\,s} = 81\,\frac{ft}{s} = 81\,fps$$

1-10

Consistency of Units in an Equation

Dimensional Analysis

- When doing statics and strengths problems, you'll often be required to determine the numerical value and the units of a variable in an equation.
- A useful method for determining the units of a variable in an equation.
- Another use of dimensional analysis is in checking the correctness of an equation which you have derived after some algebraic manipulation.

Note:

Most physical quantities can be expressed in terms of combinations of five basic dimensions. These are: mass (M), length (L), time (T), electrical current (I), and temperature (K). These five dimensions have been chosen as being basic because they are easy to measure in experiments.

Dimensions aren't the same as units. For example, the physical quantity, speed, may be measured in units of meters per second, miles per hour etc.; but regardless of the units used, speed is always a length divided by a time, so we say that the dimensions of speed are length divided by time, or simply L/T.

Similarly, the dimensions of area are L^2 since area can always be calculated as a length times a length.

For example, although the area of a circle is conventionally written as πr^2, we could write it as πr (which is a length) × r (another length).

Examples of Dimensions

Quantity	**Dimension**	**U.S. Units**	**S.I. Units**
Volume	$L \times L \times L = L^3$	ft^3	m^3
Acceleration (velocity / time)	L / T^2	ft / s^2	m / s^2
Density (mass / volume)	M / L^3	$slug / ft^3$	kg / m^3
Forces (mass x acceleration)	$M \times L / T^2$	$slug \times ft / s^2 = lb$	$kg \times m / s^2 = N$
Work (in 1-D, force x distance)	$M \times L^2 / T^2$	lb x ft	N x m
Power (work / time)	$M \times L^2 / T$	lb x ft / s	N x m / s

Important!

When solving statics and strengths problems students should form the habit of carrying units with all quantities when substituting into an equation and making sure that the result is in the correct units.

Example

A car is traveling from Chico, CA to Sacramento, CA a total distance of 90 miles. If the trip took 75 minutes, what was the vehicles speed in mph?

Solution.

$$v = \frac{L}{T} = \frac{90\ mi}{75\ min} \times \frac{60\ min}{h} = 72\ mph$$

1-11
Rules for Numerical Computations

Approximate Numbers. Although some numbers that we encounter in engineering computations are exact numbers, most numbers are approximate.

Exact Numbers. Either derived from definition or obtained by counting.

Examples:
One hour has exactly 60 minutes by definition
One inch is defined to equal 25.4 mm exactly
An automobile has four wheels by counting

Approximate numbers - usually obtained through some kind of measurement.

Examples:
The distance between two points on the ground is measured to be 237.7 ft
The voltage of a house current is measured to be 115 volts.

Approximate numbers are usually written with a decimal and often include zeros that serve as placeholders.

Examples

7400 0.0057	} These zeros are placeholders.	2005 0.708	} These zeros indicate the values of those digits are zero.

Significant Digits. Except for the zeros used as placeholders, all the other digits in an approximate number are considered significant digits.

Examples:
176
0.587
1350
3050
0.00408

} Three significant digits each.

Accuracy and Precision
Accuracy - The accuracy of a number refers to its number of significant digits.
Examples:
1570
60.9
0.0805

} Accurate to three significant digits.

Precision - The precision of a number is the decimal position of the last significant digit.
Examples:

1.35	precise to the nearest hundredths (two decimal places)
0.745	precise to the nearest thousandths (three decimal places)

Rules for Numerical Computations. When calculations are preformed on approximate numbers, the results must be expressed with the proper number of digits.

Rule 1 When approximate numbers are multiplied or divided, the result is expressed with the same accuracy as the least accurate number.

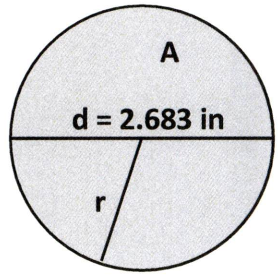
Rule 2 When approximate numbers are added or subtracted, the result is expressed with the same precision as the least precise number.

Example

The diameter of a circle measures 2.683 in. Calculate the area of the circle.

$A = \pi r^2 = \pi(d/2)^2 = \pi\, d^2 / 4$

$= 3.141592654 \times (2.683)^2 / 4$



4 Exact number, does not limit the accuracy of the result

π What is the accuracy of your calculator set to?

Calculators Accuracy	**$A = \pi\, d^2 / 4$**	**Rule 1**
3.141592654 (10 significant digits)	5.653680040 in^2	5.654 in^2
3.1415927 (8 significant digits)	5.6536800 in^2	5.654 in^2
3.14 (3 significant digits)	5.65 in^2	5.65 in^2
3.1 (2 significant digits)	5.7 in^2	5.7 in^2

Example

A steel plate 1.25 in. thick is coated with a thin layer of paint 0.014 in. thick. Of these two values of thickness, which one has a greater accuracy and which one has a greater precision?

Solution.

The number 1.25 has three significant digits, while the number 0.014 has only two significant digits. Therefore, the thickness of the plate, 1.25 in., has a greater accuracy.

On the other hand, the number 1.25 is precise to the nearest hundredths, and the number 0.014 is precise to the nearest thousandths; therefore, the thickness of the paint has a greater precision.