MEC260: Engineering Statics

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Ch1: Introduction

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Fundamental Concepts

What is Mechanics?

Mechanics is defined as a physical science that describes and predicts the conditions of rest or motion of **bodies** under the action of forces.

Mechanics of Rigid Bodies
- **Statics** deals with bodies at rest. **MEC 260**
- **Dynamics** deals with bodies in motion. MEC 262

Mechanics of Deformable Bodies MEC 363

Mechanics of Fluids
- Incompressible fluids → Hydraulics: deals with applications involving water.
- Compressible fluids → Pneumatics: deals with applications involving air.

MEC 364

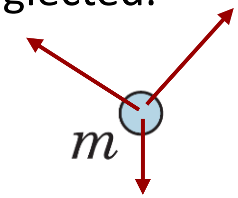
Mechanics is the foundation of most engineering sciences and applications.

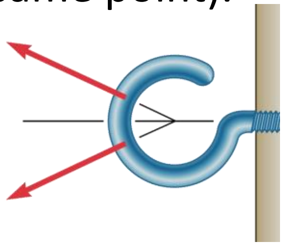
Particle and Rigid Body

There are **two** main **assumptions** for **modeling** the objects: **Particle** and **Rigid Body**.

Particle:

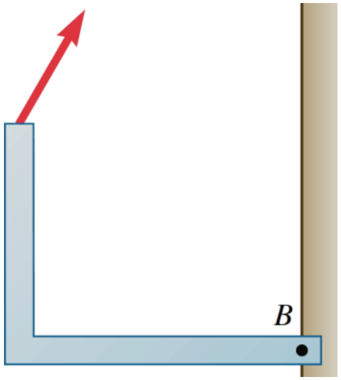
- When the sizes and shapes of the objects under consideration do not significantly affect the solutions of the problems (e.g., all forces acting on a given object act at the same point).
- By the word **Particle** we do not mean only tiny bits of matter.
- A **Particle** has a mass, but a size that can be neglected.





Rigid Body:

- When the sizes and shapes of the objects under consideration affect the solutions of the problems (e.g., forces act on different parts of the object).
- A **Rigid Body** can be considered as a combination of infinite number of tiny particles in which all the particles remain at a **fixed distance** from one another (i.e., the body does not deform).



Newton's Three Laws of Motion

Formulated by Sir Isaac Newton in the late seventeenth century, these laws can be stated as follows:

FIRST LAW. If the resultant force acting on a particle is zero, the particle remains at rest (if originally at rest) or moves with constant speed in a straight line (if originally in motion).

SECOND LAW. If the resultant force $\mathbf{F}$ acting on a particle is not zero, the particle has an acceleration $\mathbf{a}$ proportional to the magnitude of the resultant and in the direction of this resultant force: $\mathbf{F} = m\mathbf{a}$
where m is the mass of the particle.

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

Systems of Units and Conversions

Systems of Units

Two different conventional systems of units:

1. International System of Units (**S**ystème **I**nternational d'Unités or **SI**) or Metric System (in French)
2. United States Customary System (**USCS**)

✦ Both the SI and USCS are made up of seven **Base Units** and many **Derived Units**.

- **Base Units** form the core building blocks of any unit system, and they are independent of one another.
- **Derived Units** are combinations of several base units.

Quantity	SI Base Unit	Abbr.
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	Kelvin	K
Amount of substance	mole	mol
Light intensity	candela	cd

Main Distinction (Mass ↔ Force)

Quantity	USCS Base Unit	Abbr.
Length	foot	ft
Force	pound	lb or lbf
Time	second	s
Electric current	ampere	A
Temperature degree	Rankine	°R
Amount of substance	mole	mol
Light intensity	candela	cd

A Few of Derived Units in the SI

Quantity	SI Derived Unit	Abbr.	Definition
Length	micrometer or micron	μm	1 μm = 10^{-6} m
Volume	liter	L	1 L = 0.001 m^3
Force	newton	N	1 N = 1 (kg·m)/s^2
Torque, or Moment of a Force	newton-meter	N·m	—
Pressure or Stress	pascal	Pa	1 Pa = 1 N/m^2
Energy, Work, or Heat	joule	J	1 J = 1 N·m
Power	watt	W	1 W = 1 J/s
Temperature	degree Celsius	°C	°C = K – 273.15
Plane Angle	radian	rad	m·m^{-1}=1

The **newton** is defined based on Newton's second law of motion: $F = ma$

One newton of force will accelerate a one-kilogram object at the rate of one meter per second per second:

$$1\ \text{N} = (1\ \text{kg})\left(1\,\frac{\text{m}}{\text{s}^2}\right) = 1\,\frac{\text{kg}\cdot\text{m}}{\text{s}^2}$$

Standard Prefixes in the SI

Base and derived units in the **SI** are often combined with a prefix which is a **power-of-ten exponent** to shorten the representation of a numerical value and to reduce calculations.

7,000,000 W (watt) $\Rightarrow$ 7 MW (megawatt)

These prefixes are rarely used in mechanical engineering. (hecto, deca, deci)

Name	Symbol	Multiplicative Factor
tera	T	1,000,000,000,000 = 10^{12}
giga	G	1,000,000,000 = 10^{9}
mega	M	1,000,000 = 10^{6}
kilo	k	1000 = 10^{3}
hecto	h	100 = 10^{2}
deca	da	10 = 10^{1}
deci	d	0.1 = 10^{-1}
centi	c	0.01 = 10^{-2}
milli	m	0.001 = 10^{-3}
micro	μ	0.000,001 = 10^{-6}
nano	n	0.000,000,001 = 10^{-9}
pico	p	0.000,000,000,001 = 10^{-12}

A Few of Derived Units in the USCS

The USCS employs two different units for mass: **slug** and **lbm** (pound-mass).

The **slug** is defined based on Newton's second law of motion: $F = ma$

$$1\ \mathrm{lb} = (1\ \mathrm{slug})\left(1\,\frac{\mathrm{ft}}{\mathrm{s}^2}\right)$$

$$1\ \mathrm{slug} = 1\,\frac{\mathrm{lb}\cdot\mathrm{s}^2}{\mathrm{ft}}$$

Quantity	USCS Derived Unit	Abbr.	Definition
Length	mil	mil	1 mil = 0.001 in.
	inch	in.	1 in. = 0.0833 ft
	mile	mi	1 mi = 5280 ft
Volume	gallon	gal	1 gal = 0.1337 ft^3
Mass	slug	slug	1 slug = 1 $(\mathrm{lb}\cdot\mathrm{s}^2)/\mathrm{ft}$
	pound-mass	lbm	1 lbm = 3.1081×10^{-2} $(\mathrm{lb}\cdot\mathrm{s}^2)/\mathrm{ft}$
Force	ounce	oz	1 oz = 0.0625 lb
	ton	ton	1 ton = 2000 lb
Torque, or moment of a force	foot-pound	ft·lb	—
Pressure or stress	$\mathrm{pound/inch}^2$	psi	1 psi = 1 $\mathrm{lb/in}^2$
Energy, work, or heat	foot-pound	ft·lb	—
	British thermal unit	Btu	1 Btu = 778.2 ft · lb
Power	horsepower	hp	1 hp = 550 (ft · lb)/s
Temperature	degree Fahrenheit	°F	°F = °R – 459.67
Plane Angle	radian	rad	$\mathrm{ft}\cdot\mathrm{ft}^{-1}=1$

Converting Between the SI and USCS

A numerical value in one unit system can be transformed into an equivalent value in the other system by using **unit conversion factors**.

Quantity	Conversion
Length	1 in. = 25.4 mm 1 in. = 0.0254 m 1 ft = 0.3048 m 1 mi = 1.609 km 1 mm = 3.9370×10^{-2} in. 1 m = 39.37 in. 1 m = 3.2808 ft 1 km = 0.6214 mi
Area	1 in^2 = 645.16 mm^2 1 ft^2 = 9.2903×10^{-2} m^2 1 mm^2 = 1.5500×10^{-3} in^2 1 m^2 = 10.7639 ft^2
Volume	1 ft^3 = 2.832×10^{-2} m^3 1 ft^3 = 28.32 L 1 gal = 3.7854×10^{-3} m^3 1 gal = 3.7854 L 1 m^3 = 35.32 ft^3 1 L = 3.532×10^{-2} ft^3 1 m^3 = 264.2 gal 1 L = 0.2642 gal

Quantity	Conversion
Mass	1 slug = 14.5939 kg 1 lbm = 0.45359 kg 1 kg = 6.8522×10^{-2} slugs 1 kg = 2.2046 lbm
Force	1 lb = 4.4482 N 1 N = 0.22481 lb
Pressure or stress	1 psi = 6895 Pa 1 psi = 6.895 kPa 1 Pa = 1.450×10^{-4} psi 1 kPa = 0.1450 psi
Work, energy, or heat	1 ft·lb = 1.356 J 1 Btu = 1055 J 1 J = 0.7376 ft · lb 1 J = 9.478×10^{-4} Btu
Power	1 (ft·lb)/s = 1.356 W 1 hp = 0.7457 kW 1 W = 0.7376 (ft · lb)/s 1 kW = 1.341 hp

Mass and Weight

Mass is an **intrinsic property** of an object based on the amount and density of material from which it is made. Mass does not vary with position, motion, or changes in the object's shape.

Units: kg (in SI), slug and lbm (in USCS)

Weight is the **force** that is needed to support the object against gravitational attraction, and it is calculated as

$$w = mg$$

- w: weight
- m: mass
- g: Earth's gravitational acceleration constant

g = 9.8067 m/s^2, g = 32.174 ft/s^2

≈ 9.81 ≈ 32.2

Units: N (in SI), lb or lbf (in USCS)

On Earth, an object having a mass of:

- 1 kg weighs 9.8067 N
- 1 slug weighs 32.174 lb
- 1 lbm weighs 1 lb