University of Victoria Engineering

Chapter 1 – General Principles

Contents

Engineering Mechanics (§ 1.1)

Fundamental Principles (§ 1.2)

Measurement in Engineering

Units of Measurements in Mechanics (§ 1.3)

Numerical Calculations (§ 1.5)

Large cranes such as this one are required to lift extremely large loads. Their design is based on the basic principles of statics and dynamics, which form the subject matter of engineering mechanics.

Please refrain from uploading course materials onto online sharing platforms, such as Course Hero, OneClass or equivalent sharing platforms.

Engineering Mechanics

Engineering Mechanics

Statics is a branch of mechanics.

Mechanics: study of the state of rest or motion of bodies subjected to applied forces.

Mechanics

Rigid bodies

Deformable bodies

Statics	Dynamics	Solids	Fluids
ENGR 141	MECH 242	MECH 220	MECH 345
	MECH 330	MECH 320	MECH 493
	MECH 421	MECH 421	MECH 494

Engineering Mechanics

Basic Quantities in Mechanics:

Length, Time (dynamics), Mass and Force.

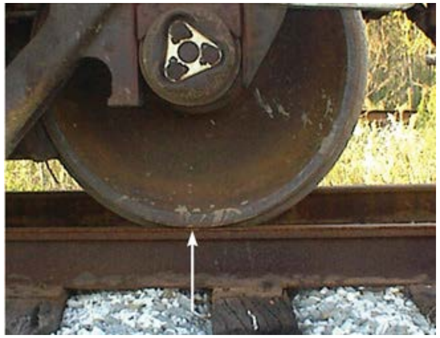
Idealizations (to simplify theory application):

- Particle – A particle has a mass, but the size can be neglected. Some bodies can be idealized as particles.

Ring is idealized as a particle

- Rigid Body – A rigid body is a combination of a large number of particles that remain at a fixed distance from one another. We will neglect small deformations

- Concentrated Force – A concentrated force acts at one point of the body. We will assume a concentrated force if the area of contact is very small compared to the size of the body.



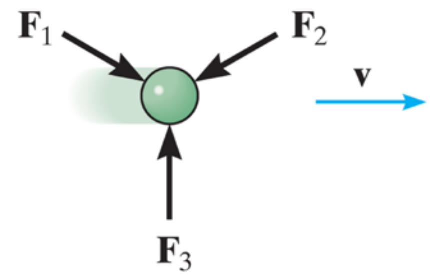
Wheel is assumed as rigid body acted upon a concentrated force

Fundamental Principles

Fundamental Principles

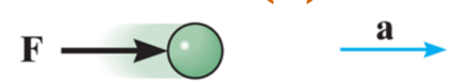
Newton’s Three Laws of Motion

First Law: A particle will remain at rest or moving in a straight line with a constant velocity if it is NOT acted upon by an unbalanced external force



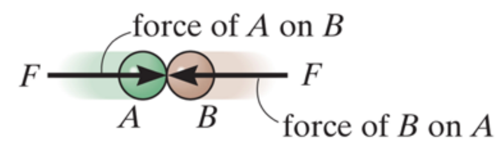
Second Law: A particle acted upon by an unbalanced force F experiences an acceleration that has the same direction as F and is inversely proportional to its mass

F = m(a)



Accelerated motion

Third Law: Forces of action and reaction between two bodies are equal, opposite and collinear.



Action – reaction

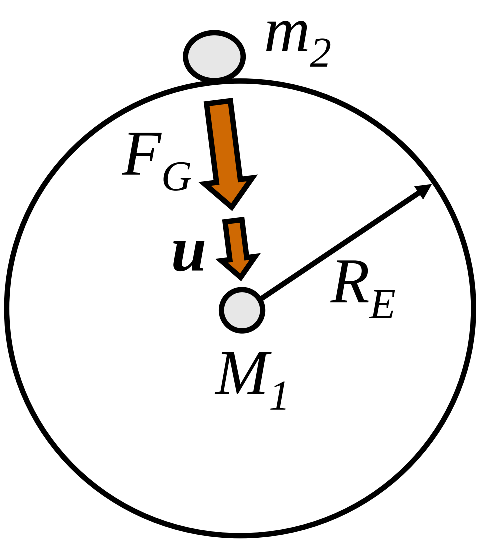
Netwon’s three laws apply to particles, not rigid bodies.

Fundamental Principles

Newton's Law of Gravitational Attraction

A particle exerts a gravitation force on another particle that is proportional to the mass of each particle.

In ENGR 141, the Earth is one "particle" for which this attractive force significantly affects static and dynamic analyses of rigid bodies.



$$F_G = m_2 \left(\frac{G M_1}{{R_E}^2} \right) \boldsymbol{u} = m_2 \boldsymbol{g}$$

$$|\boldsymbol{g}| = 9.81 \ \frac{\text{m}}{\text{s}^2}$$

or

$$|\boldsymbol{g}| = 32.2 \ \frac{\text{ft}}{\text{s}^2}$$

$$G = 66.73 \times 10^{-12} \ \frac{m^3}{kg \cdot s^2}$$

$$R_E \approx 6.37 \times 10^6 \ \text{m}$$

$$\text{M}_1 \approx 5.972 \times 10^{24} \ \text{kg}$$

G Universal constant of gravitation
R_E Earth radius
M_1 Earth mass

Fundamental Principles

Weight

Consider a particle *m* influenced by only the Earth's gravitational attraction. Newton's Law of Gravitational Attraction defines this attractive force.

If the particle is not subject to any other applied force, it will accelerate according to Newton's Second Law

That acceleration is 9.81 m/s^2, no matter the mass of the particle.

$$\boldsymbol{F}_G = m\left(\frac{GM_1}{R_E{}^2}\right)\boldsymbol{u} = m(\boldsymbol{a})$$

$$|\boldsymbol{a}| = |\boldsymbol{g}| = 9.81\ \frac{\mathrm{m}}{\mathrm{s}^2}$$

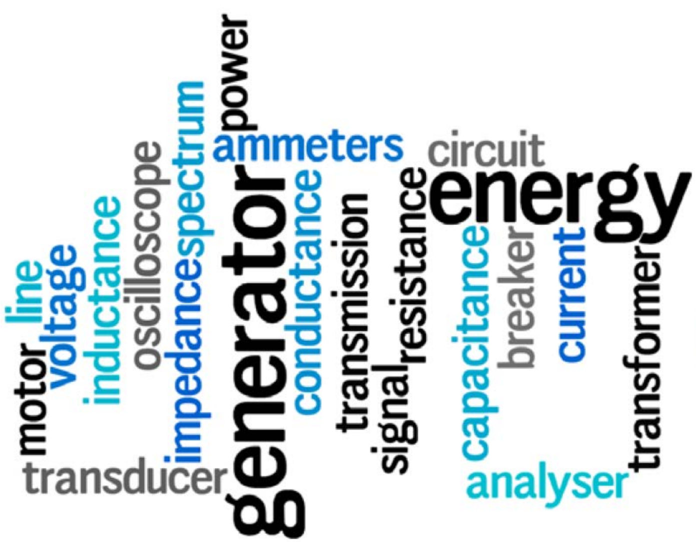
'Weight' can be used as an indicator of 'mass'

$$m = \frac{|\boldsymbol{F}|_G}{|\boldsymbol{g}|}$$

Measurement in Engineering

Measurement in Engineering

The action of measuring something where ‘measuring’ ascertains the size, amount or degree (of something) by using an instrument or device marked in standard units.



Many parameters need to be measured by an engineer

Measurement in Engineering

Our lives rely heavily on precision measurement:

- Satellite navigation systems depend on ultra-stable clocks, as any small error in timing can throw navigation a long way off course.
- Nuts ordered from one supplier will fit together and work with bolts ordered from another.

Every measurement is a comparison between a quantity we want to know about and a standard amount of that quantity.

There are international standard organizations that define standards (BIPM, ISO, ASME, IEEE, etc.)

Each country has institutes of standards which ensure that a specific measurement (e.g. 1 kg) is actually that quantity.

Legal codes (building) are established to protect our society.

Measurement in Engineering

Measurement Standards

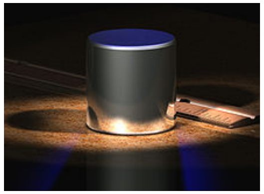
There is a three-level hierarchy of physical measurement standards.

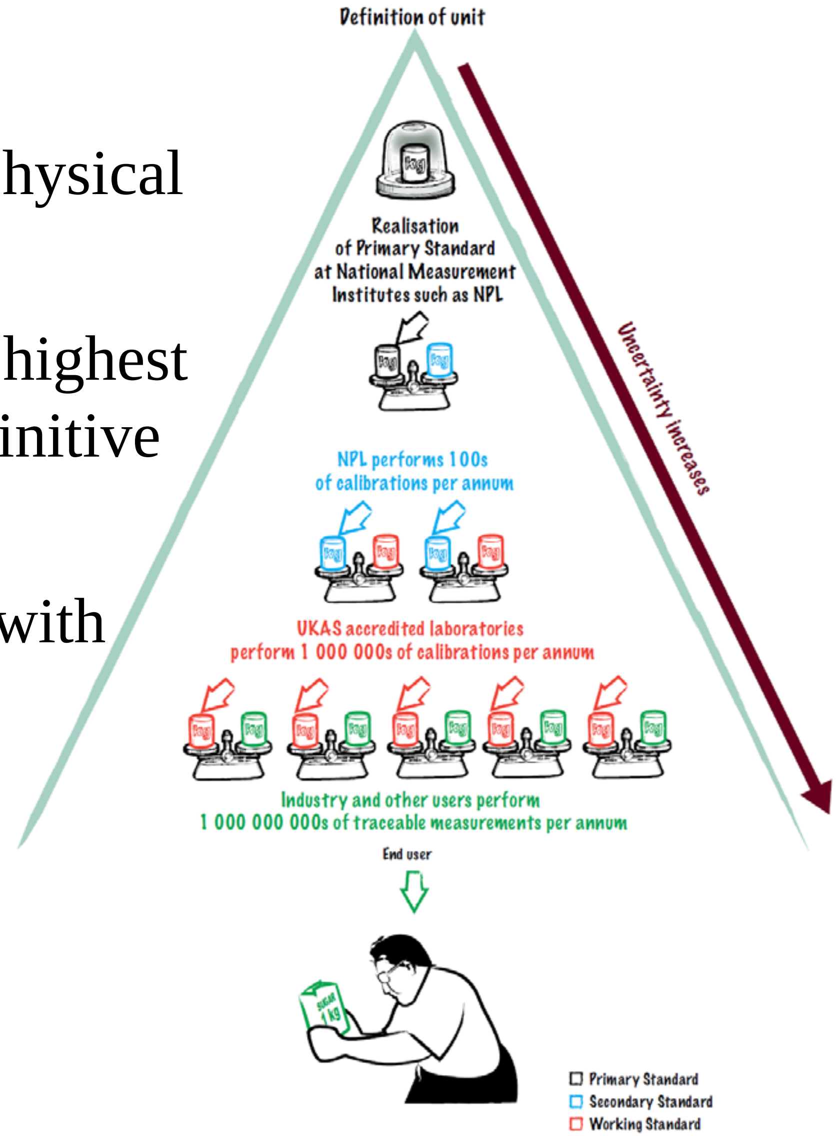
Primary Standards: are made to the highest metrological quality and are the definitive definition of their unit of measure.

Secondary standards are calibrated with reference to the primary standard.

Working standards are used for the calibration of commercial and industrial measurement equipment

For example, the international prototype kilogram (IPK)





Measurement in Engineering

Simple measurement mistakes, such as units, can be very costly!

The **Laufenburg Bridge** connects Switzerland and Germany. Both countries built half of the bridge relative to the sea level. Germany used the North Sea and Switzerland the Mediterranean Sea. By the time the two half-bridges met, there was a 54 cm difference.

The **Great Kersten Blunder**. Software controlling the Vigor space probe, on course for Venus, used 24.5 instead of 25.4 to convert millimetres to inches. The error meant that the probe missed Venus completely, and $2 billion worth of technology was lost. The eponymous Kersten was the programmer who made the error.

Tokyo Disneyland's Space Mountain Derailment. The Space mountain roller coaster ride broke an axle during the middle of the ride causing one of the two roller coaster cars to derail (2003). The reason: an incorrect conversion from Imperial to SI units.

Measurement in Engineering

NASA's Mars Climate Orbiter programming teams in Europe and the USA used two different measurement systems to calculate the trajectory of the spacecraft. The probe consequently entered the Martian atmosphere at the wrong angle, and promptly disintegrated.

The **‘Gimli Glider’** is referred to an Air Canada flight incident from Montreal to Edmonton (July 1983). The aircraft was refuelled in Montreal using an incorrect conversion.

22,300 kg (required) − 13,597 lb (in tanks) = 8,703 kg (refuel)

When the plane ran out of fuel mid-flight, the pilot had to make an emergency 'gliding' landing at Gimli (Manitoba) Canadian Air Force Base.

Measurement in Engineering

International System of Units

There are seven base units.

SI		
Quantity	**SI unit**	**Symbol**
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin or degree Celsius	K or °C
Luminous intensity	candela	cd
Amount of substance	mole	mol

All measurements can be expressed using combinations of the seven base units.

Derived units - examples		
Quantity	**Unit**	**Symbol**
Area	square metre	m^2
Volume	cubic metre	m^3
Speed	metre per second	$m\ s^{-1}$ or m/s
Acceleration	metre per second per second	$m\ s^{-2}$ or m/s^2
Force	newton	N
Energy	joule	J
Power	watt	W

Measurement in Engineering

Prefixes

SI prefixes

Prefix	Symbol	Decimal	Power of 10
yotta	Y	1 000 000 000 000 000 000 000 000	10^{24}
zetta	Z	1 000 000 000 000 000 000 000	10^{21}
exa	E	1 000 000 000 000 000 000	10^{18}
peta	P	1 000 000 000 000 000	10^{15}
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	1 000	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}
femto	f	0.000 000 000 000 001	10^{-15}
atto	a	0.000 000 000 000 000 001	10^{-18}
zepto	z	0.000 000 000 000 000 000 001	10^{-21}
yocto	y	0.000 000 000 000 000 000 000 001	10^{-24}

Units of Measurement in Mechanics

Units of Measurement in Mechanics

Newton’s second Law states that acceleration of a particle is linearly proportional to the applied force (mass is constant).

Newton’s second Law relates the four physical quantities that govern mechanics. However, not all four physical quantities are independent.

In order to maintain the equality, three quantities must be *defined*, called **based units**, and the fourth unit must be *derived* from the equation.

$$\mathbf{F} = m\,\mathbf{a}$$

F

M

L/T^2

Units of Measurement in Mechanics

International System of Units (SI Units)

The International System of Units, defines the base units as: length in meters (m), time in seconds (s), and mass in kilograms (kg). The unit of force is called a newton (N), and it is derived from **F =** m **a**

$$N = kg \cdot m/s^2$$

Thus, 1 newton is equal to a force required to give 1 kilogram of mass an acceleration of 1 m/s^2.

Note: A scale does not measure mass directly, it measures weight (force). Once a scale is calibrated for a particular acceleration (gravity), it reports the measurement in mass units (kilograms).

Units of Measurement in Mechanics

Foot-Pound-Second System (FPS)

The FPS (Imperial Units / U.S. Customary) system of units measures the base units as: force in pounds (lbf), length in feet (ft), time in seconds (s). These are the are the *defined* or independent quantities.

A unit of mass (the "slug") is the amount of mass that is accelerated at a unit amount (1 ft/s^2) when acted upon by a unit force (1 lbf). The slug is a derived unit

$$slug = lbf \cdot s^2/ft$$

A misleading term that is sometimes used is the "pound mass" (lbm).

$$F_g = m \cdot 32.2\ \text{ft/s}^2 \;\Rightarrow\; \text{let } F_g = 1\ \text{lbf}\ \ (\text{and thus } m = 1\ \text{lbm})$$

$$\therefore 1\ \text{lbm} = \frac{1\ \text{lbf}}{32.2\ \text{ft/s}^2} = .0311\ \text{slugs}$$

When using lbm, divide the lbm mass amount by 32.2 to convert it into slugs

Units of Measurement in Mechanics

Summary of Units of Measurements

Name	Length	Time	Mass	Force
International System of Units SI	meter m	second s	kilogram kg	newton* N $\left(\dfrac{kg \cdot m}{s^2}\right)$
U.S. Customary FPS	foot ft	second s	slug* $\left(\dfrac{lb \cdot s^2}{ft}\right)$	pound lb

*Derived unit.

Units of Measurement in Mechanics

Conversions

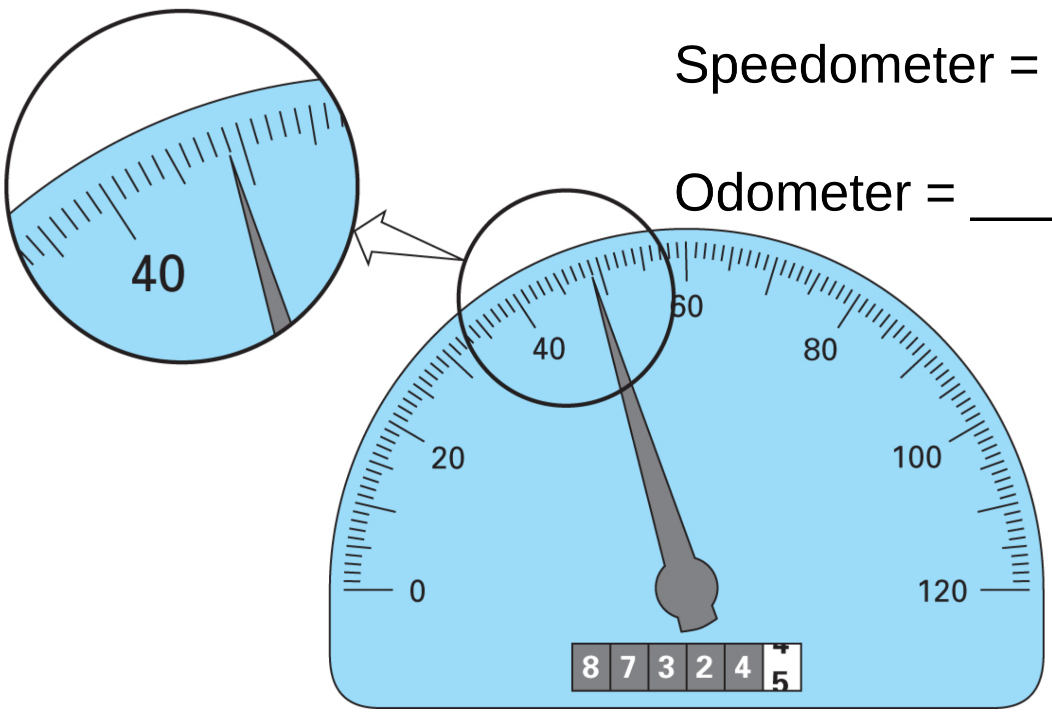
Quantity	Unit of Measurement (FPS)	Equals	Unit of Measurement (SI)
Force	lb		4.448 N
Mass	slug		14.59 kg
Length	ft		0.3048 m

Work problems in the units given unless otherwise specified!

Numerical Calculations

Significant Figures

The number of significant figures determine the precision of accuracy of the number. These are the numbers that we can use with confidence.



Speedometer = ____________

Odometer = _______________

Numerical Calculations

It is important to recognize that the number of significant figures are associated with the engineering notation.

Reporting zeros using engineering notation is important, as we report our confidence to those digits, e.g., number 53,800 can be expressed as

5.38×10^{4}	3 significant figures
5.380×10^{4}	4 significant figures
5.3800×10^{4}	5 significant figures

Zeros after the decimal point are not significant figures.

0.00001753	=	1.753×10^{-5}	4 significant figures
0.0001753	=	1.753×10^{-4}	4 significant figures
0.001753	=	1.753×10^{-3}	4 significant figures

Infinite numbers such as π or e represent specific quantities. Because computers retain only a finite number, the number is truncated leading to **round-off errors**.

Numerical Calculations

Calculations and Reporting Results

When a sequence of calculations is carried out, it is best to store the intermediate results in a calculator, to minimize round off errors.

For the final result, we will report it using <u>three significant figures.</u>

- If the fourth figure is greater than 5, round up the third figure.
- If the fourth figure is less than 5, round off.
- If the fourth figure is a 5, round up if the preceding digit (third digit) is an odd number, round off if the preceding digit is an even number.

Examples,

1.341 ➡ 1.34	75.25 ➡ 75.2 (5 is preceded by a 2)
9.3866 ➡ 9.39	0.1275 ➡ 0.128 (5 is preceded by 7)